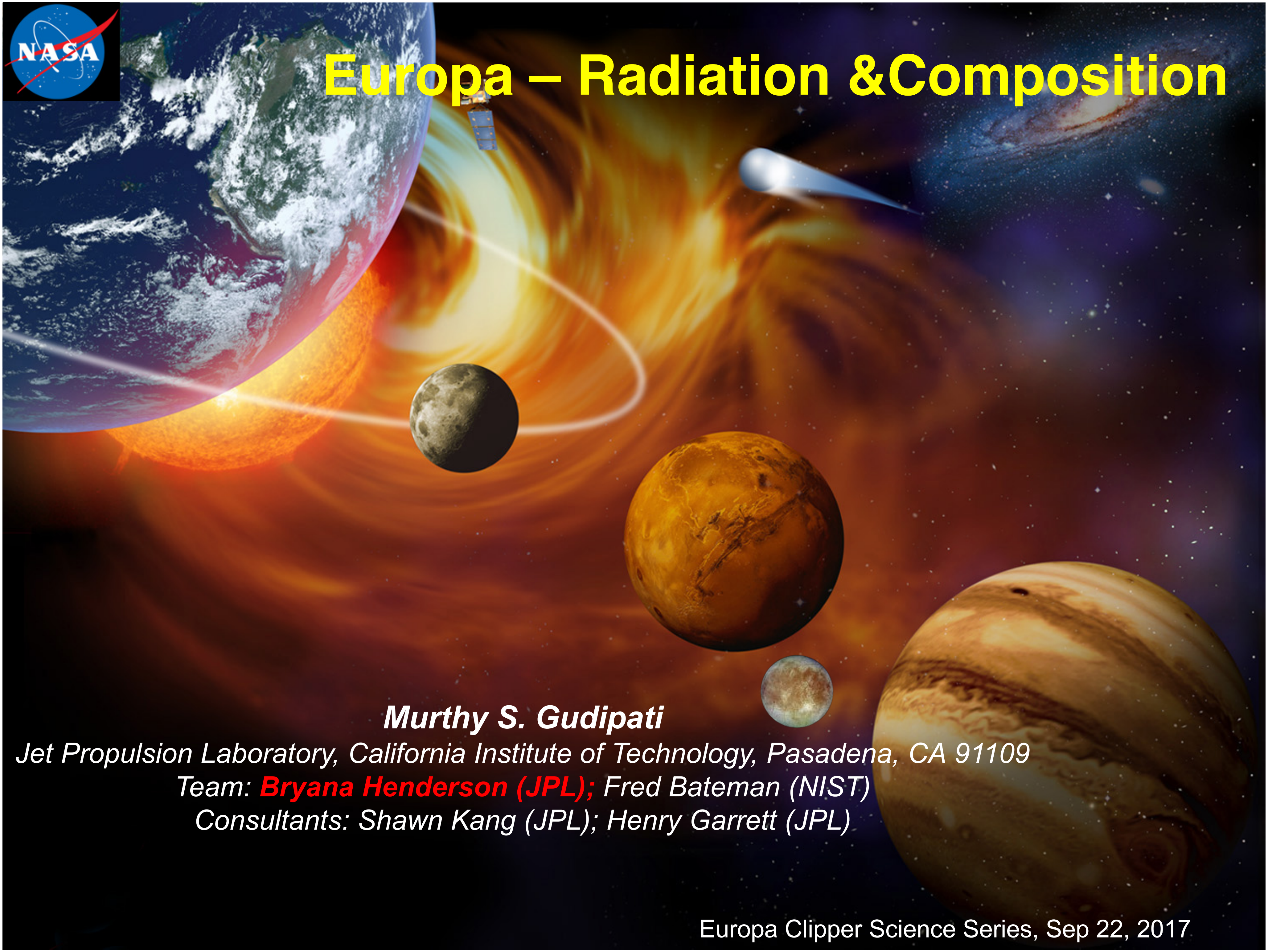

Europa – Radiation &Composition

Murthy S. Gudipati

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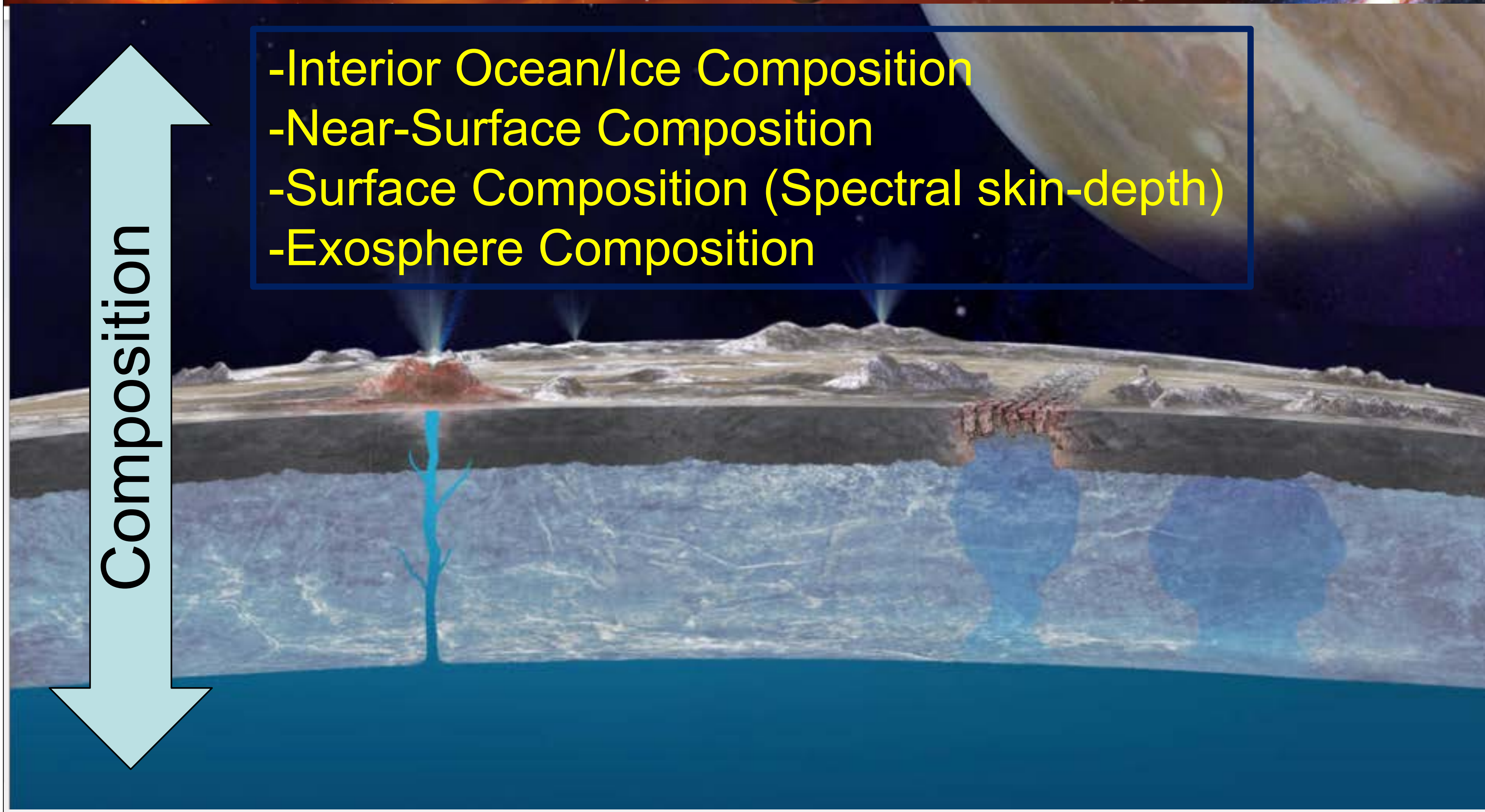
*Team: **Bryana Henderson (JPL);** Fred Bateman (NIST)*

Consultants: Shawn Kang (JPL); Henry Garrett (JPL)

Europa Clipper Science Series, Sep 22, 2017

Composition



If present & detected, plumes directly connect interior composition to surface and exosphere

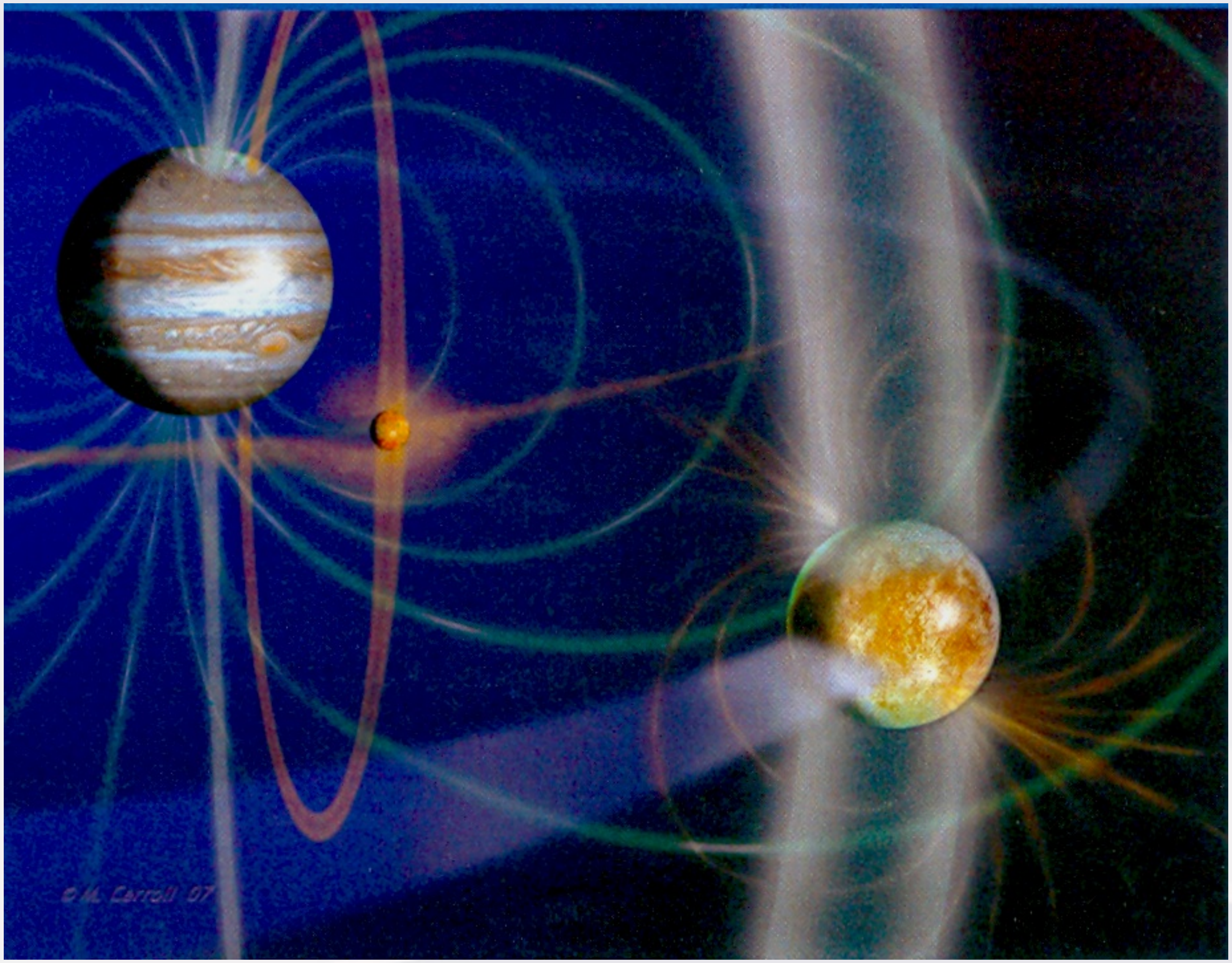
Europa – Composition & Radiation

- Plumes connect interior composition directly to surface and exosphere.
- For transport of any other kind, radiation alters the observed vs. expected composition of the interior.
- The extent of radiation altering is determined by the frequency of upwelling/renewing the surface.

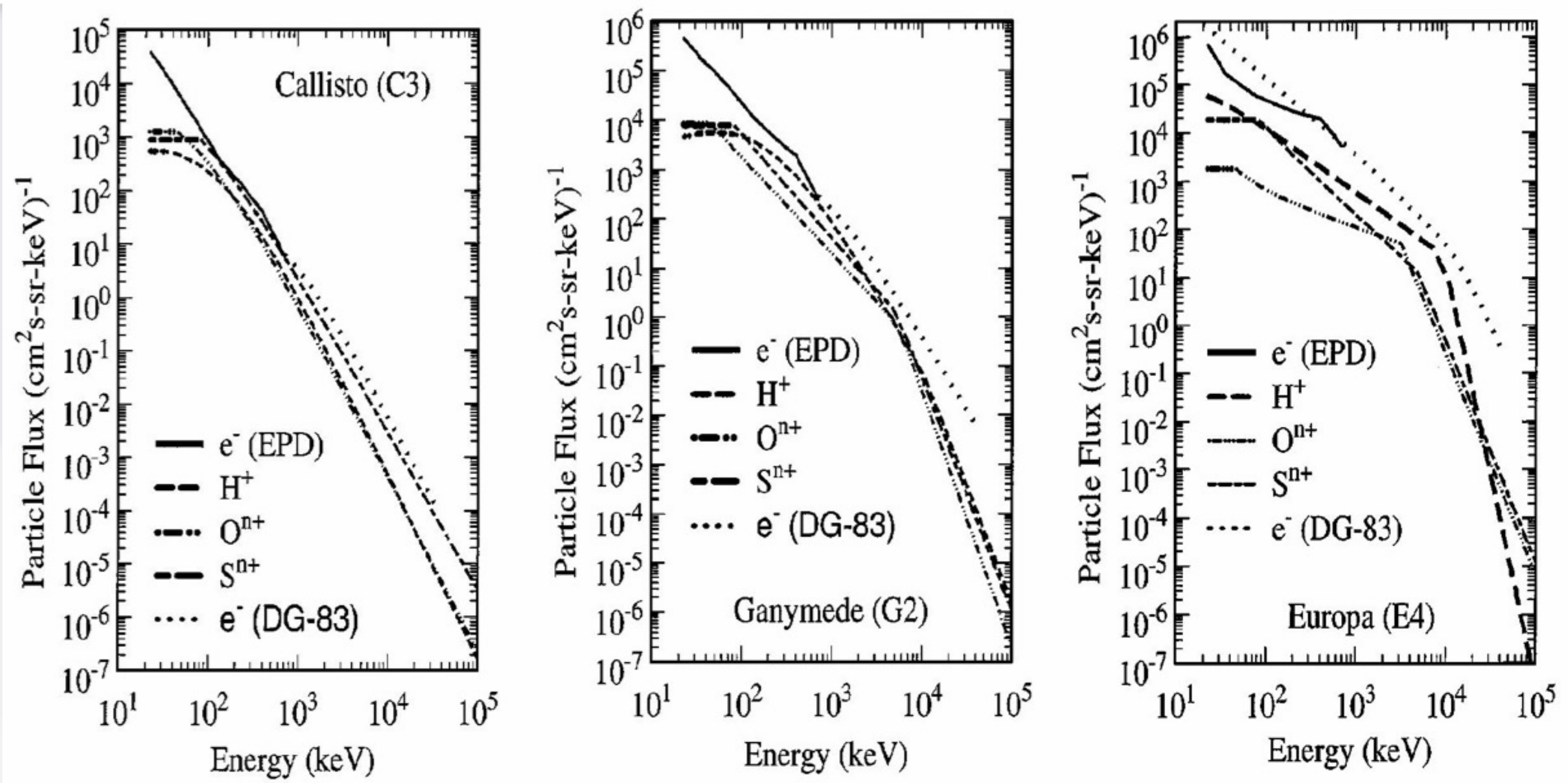
Radiation & Composition of Europa are Inseparable!

Radiation Environmnet of Europa

Electrons Reaching Europa's Surface: Trailing (colored) Hemisphere: **<25 MeV**; Leading Hemisphere: **>25 MeV**



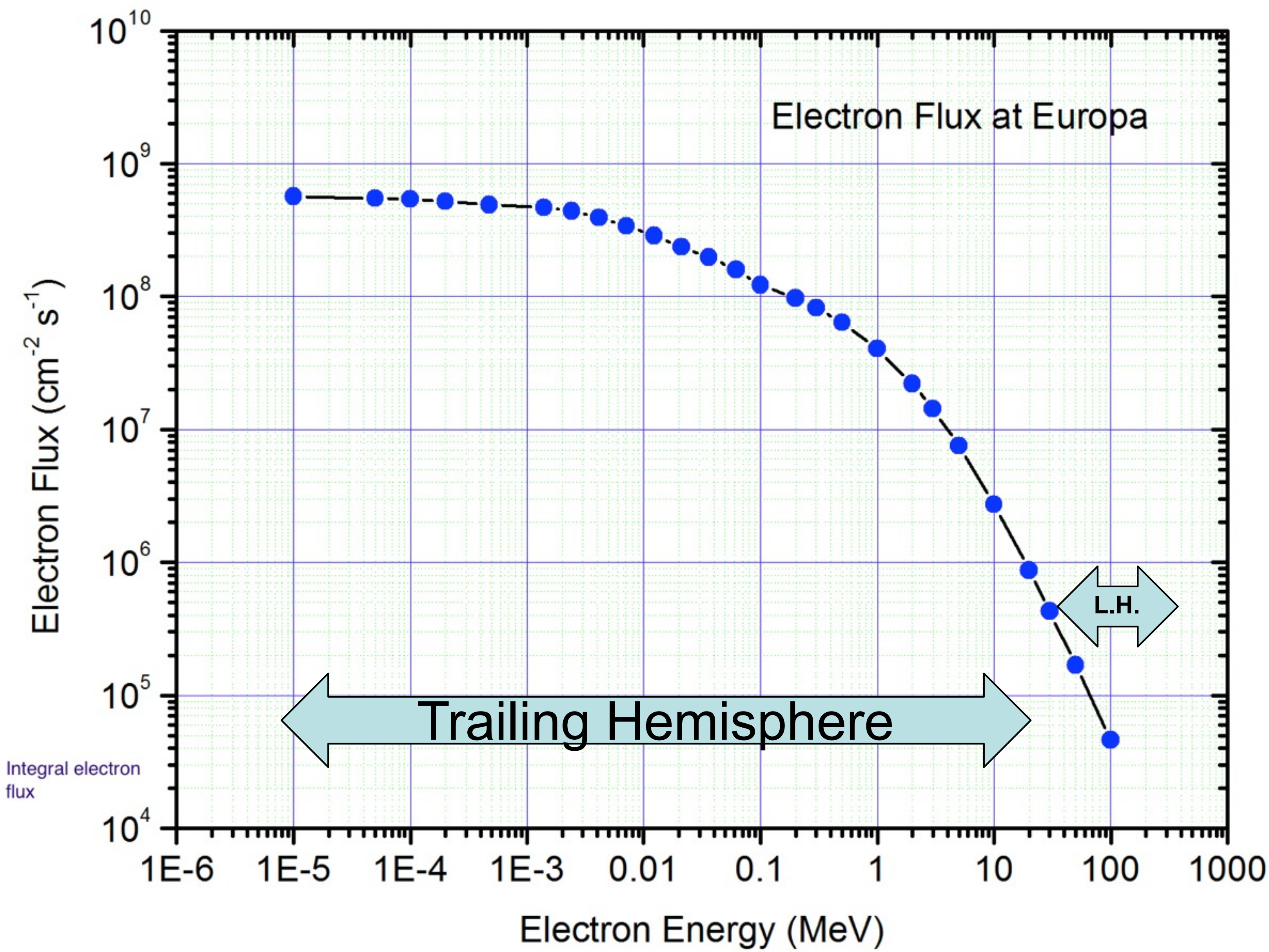
Europa Radiation Environment



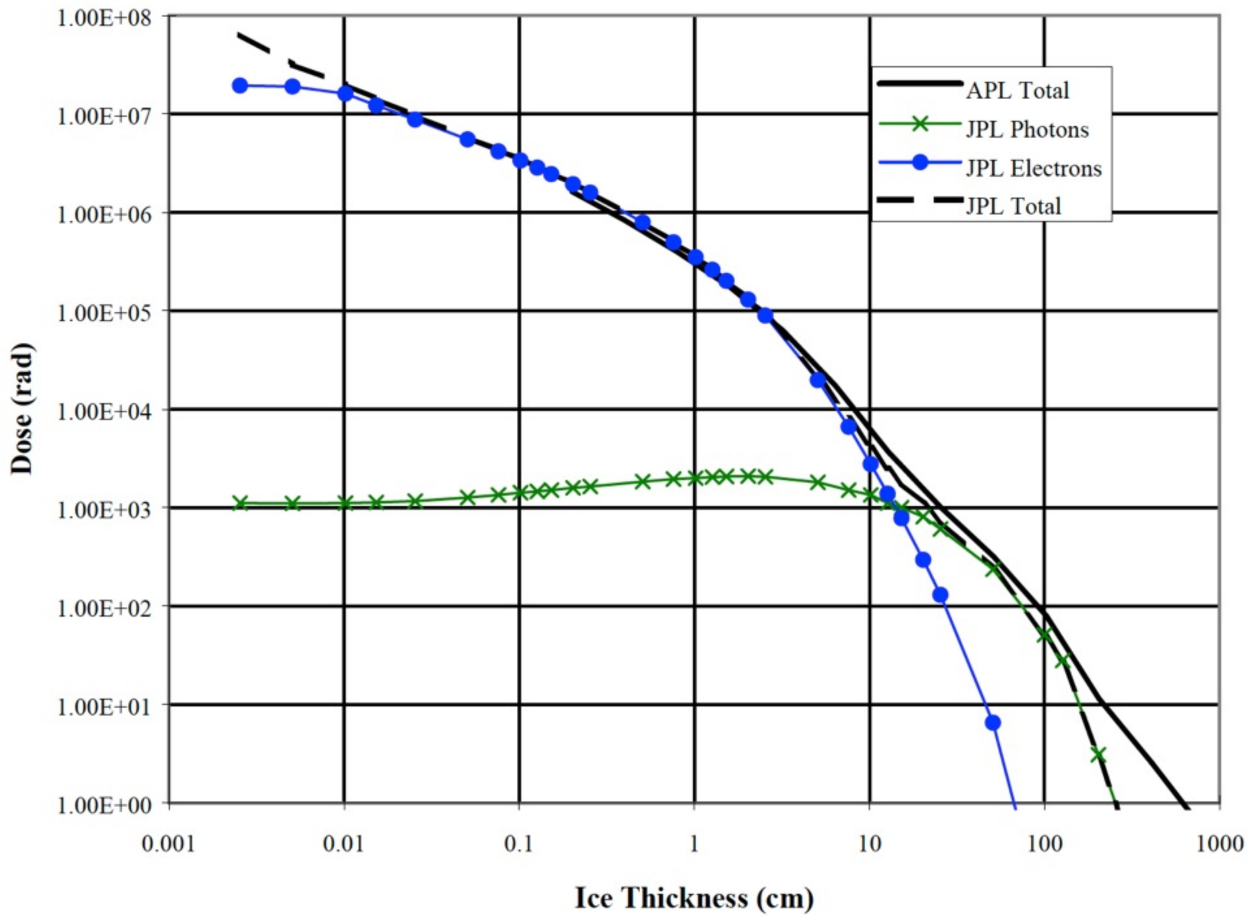
Galileo Orbiter measurements of energetic ions (20 keV to 100 MeV) and electrons (20–700 keV) in Jupiter's magnetosphere are used in conjunction with the JPL electron model (<40 MeV) to compute irradiation effects in the surface layers of Europa, Ganymede, and Callisto. Significant elemental modifications are produced on unshielded surfaces to approximately centimeter depths in times of 10^6 years, whereas micrometer depths on Europa are fully processed in <10 years.

John Cooper et al. Icarus (2001)

Electron Flux at Europa



Europa - Radiation Environment (Models)

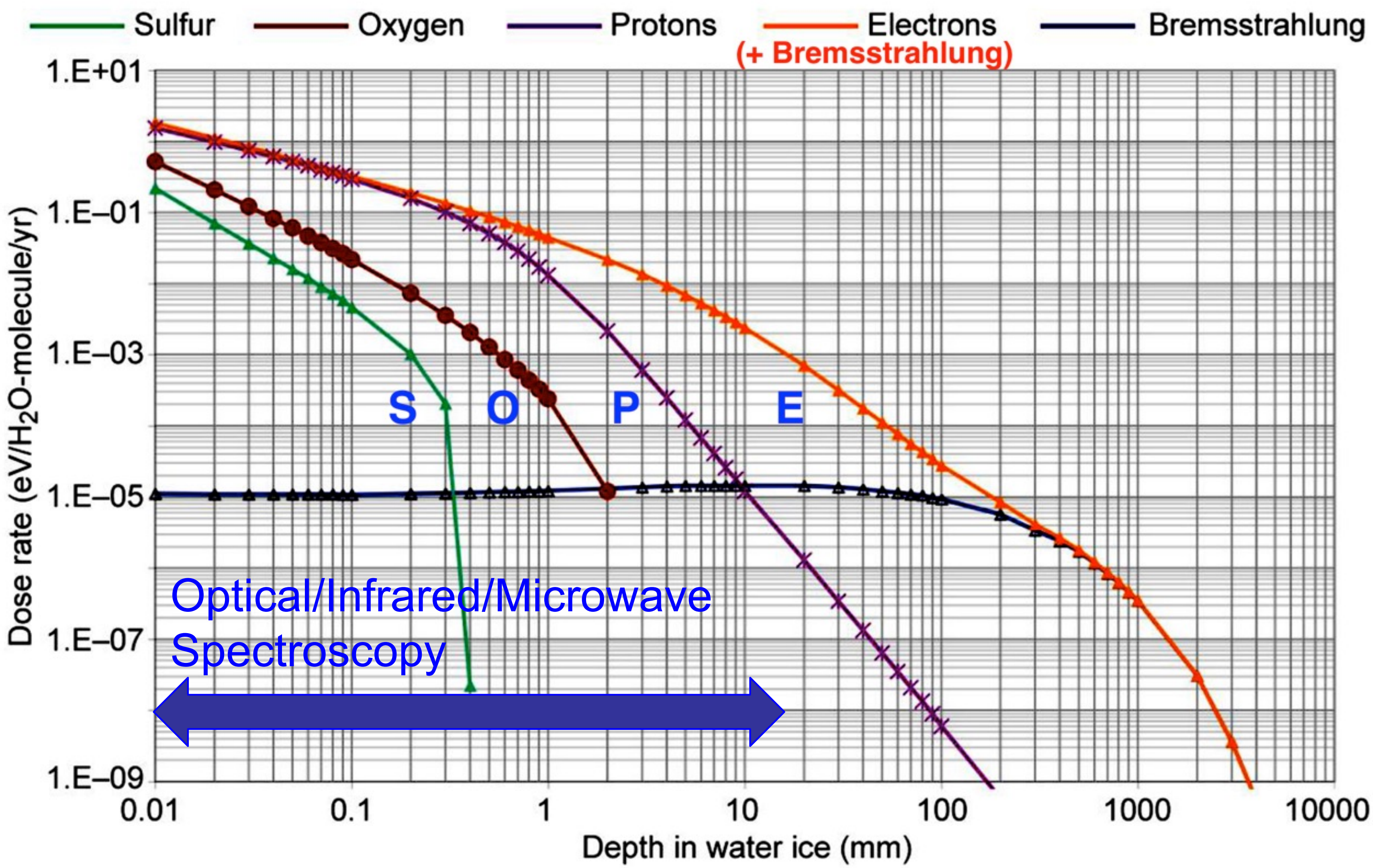


Preventing the Forward Contamination of Europa, National Academy of Sciences Report, 2000.

FIGURE 2.3 Radiation dose models for Europa, in rad [water] per month (30.4 days) of exposure below varying thicknesses of ice. The results of two independent evaluations are given, "JPL Total" and "APL Total." For the JPL Total model, the separate contributions of electrons and photons (bremsstrahlung) are shown. The APL Total model has higher proton fluxes at very high energies. In addition to the theoretical uncertainties in Europa's radiation environment (as indicated by the differences between the APL and JPL models), natural variations of up to an order of magnitude have been observed in Jupiter's trapped-particle intensities over the 25-year span between the Pioneer and Galileo missions. Information provided by J.M. Ratliff of the Jet Propulsion Laboratory and C.P. Paranicas of the Applied Physics Laboratory, Johns Hopkins University.

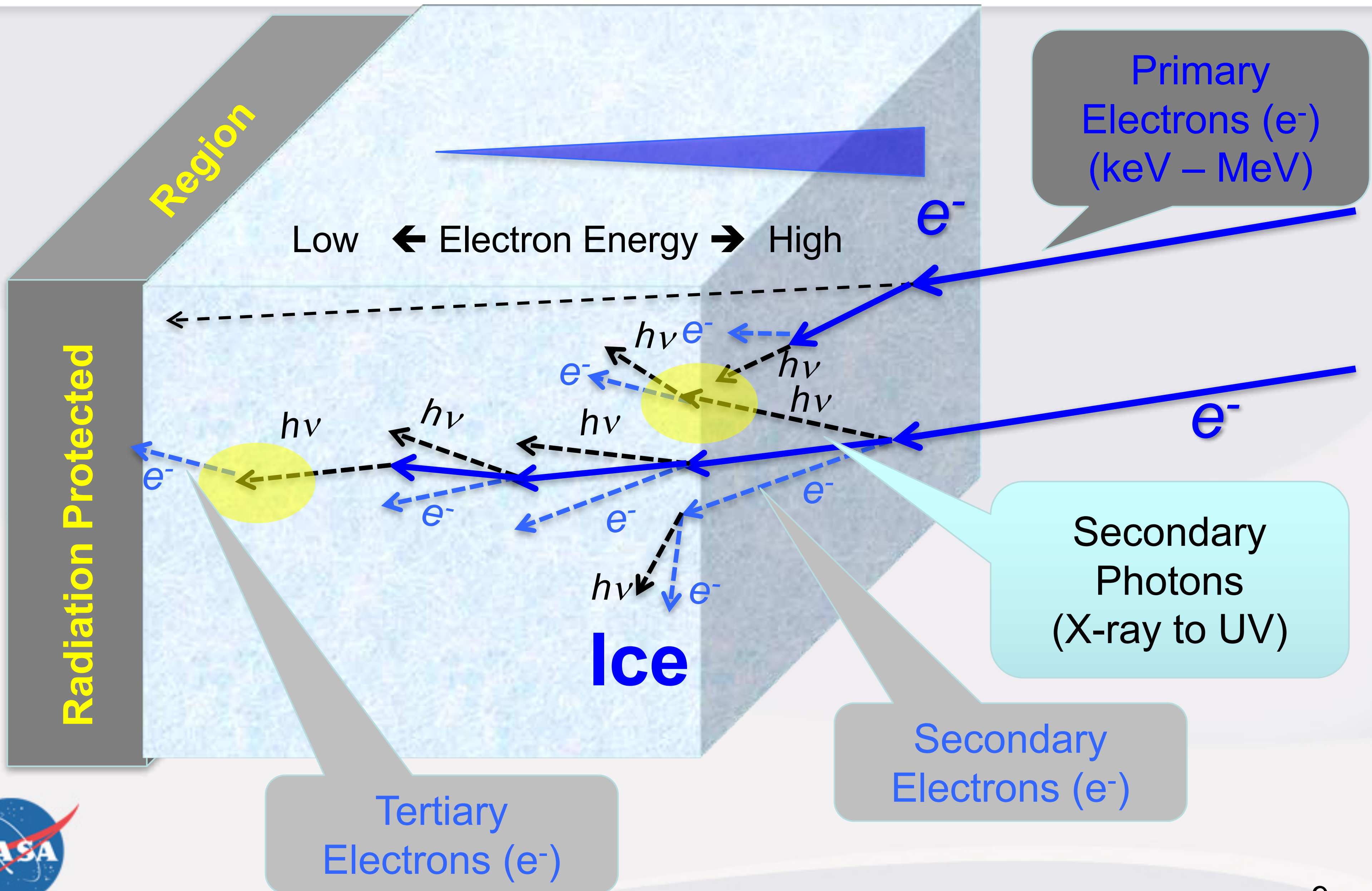
Modeling Europa's Radiation Dose

Based on liquid water or empirical data – no lab data YET published



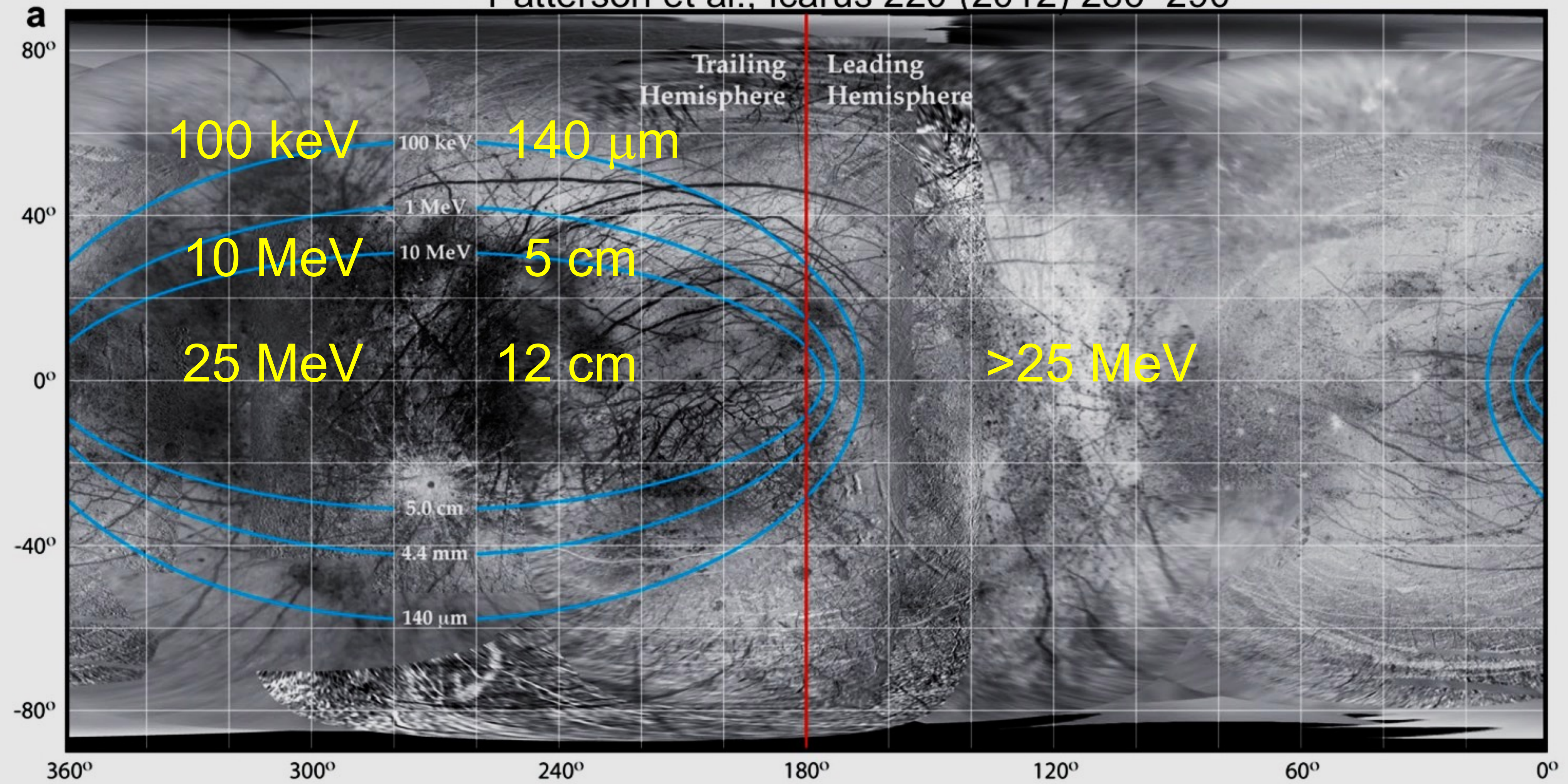
Plot from: Paranicas et al. (2002)

Electron Impact on Matter: Primary and Secondary Radiation



Electron Radiation on Europa's Surface: Models

Patterson et al., Icarus 220 (2012) 286–290

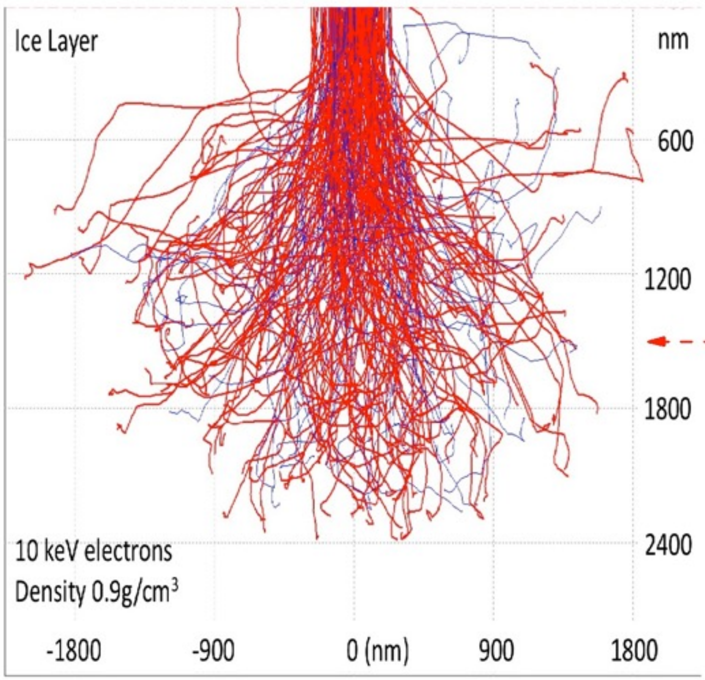


100 keV ~140 µm; 1 MeV ~4.4 mm; 10 MeV ~ 5 cm
Bremsstrahlung penetrates ~20 times deeper

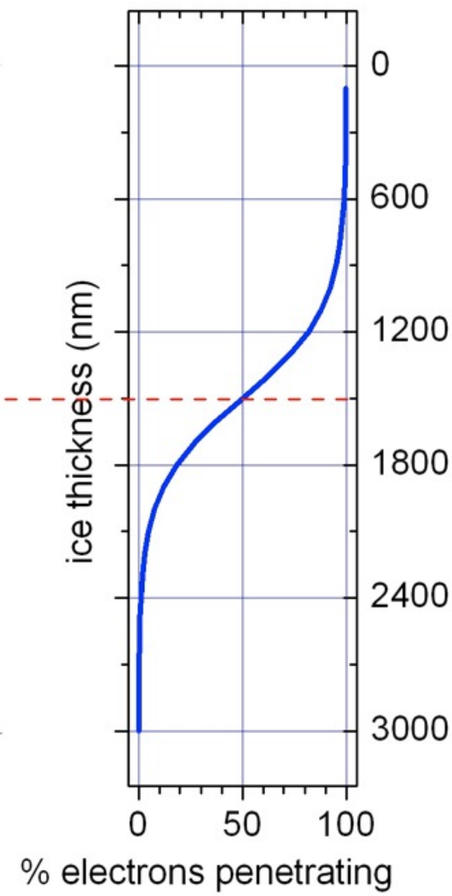
Penetration of Electrons in Ice is Statistical: Modeling

CASINO:
Hovington et al. Scanning 19 (1997) 29

Li Barnett, Lignell, Gudipati ApJ 747:13 (11pp), 2012



CASINO simulations for penetration paths of 10 keV electrons through ice of 0.9 g/cm^3



Sigmoidal not a Delta Function

Electron penetration into ice is a statistical phenomenon – that can be approximated by a sigmoidal equation (probability):

$$y = \frac{A_1 - A_2}{1 + e^{(x-x_0)/dx}} + A_2$$

Penetration depths must have percentile qualifier.

The default is 50% of the particles (electrons).

The rest of the 50% make to further depths.

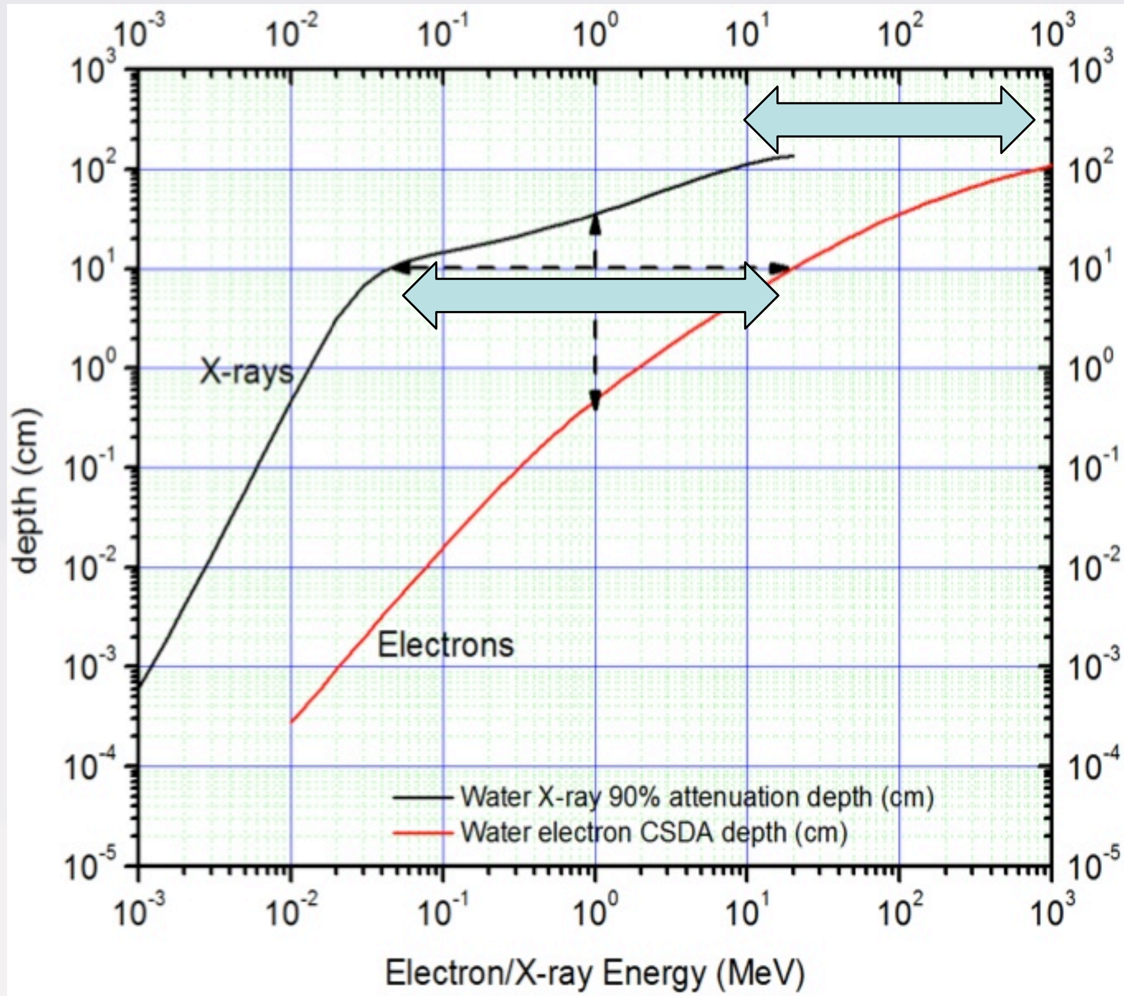
50% of 25 MeV electrons penetrate deeper than 12 cm

Penetration Depths of Bremsstrahlung (X-rays)

	100 keV	1 MeV	10 MeV
Electrons:	~140 μm	~4.4 mm	~ 5 cm
X-rays:	~15 cm	~30 cm	~100 cm

100 cm

10 cm



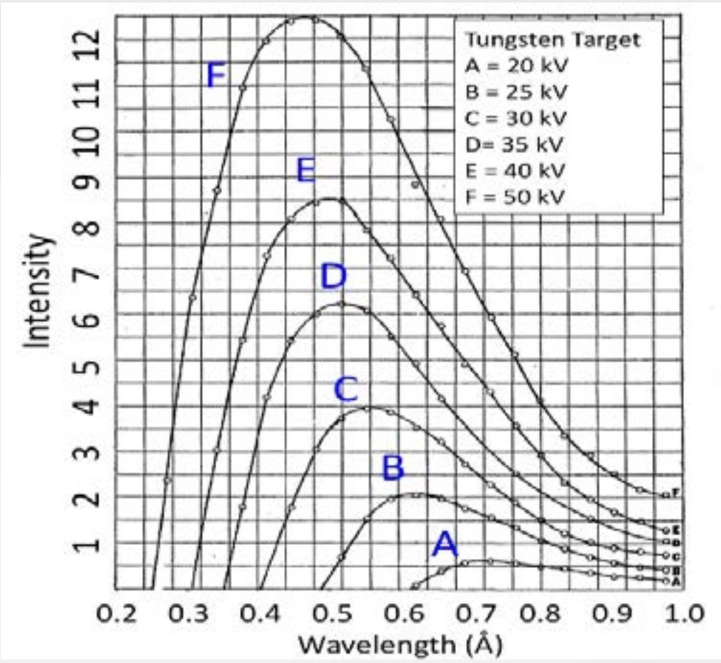
10 cm penetration:
20 MeV electrons or
50 keV X-rays

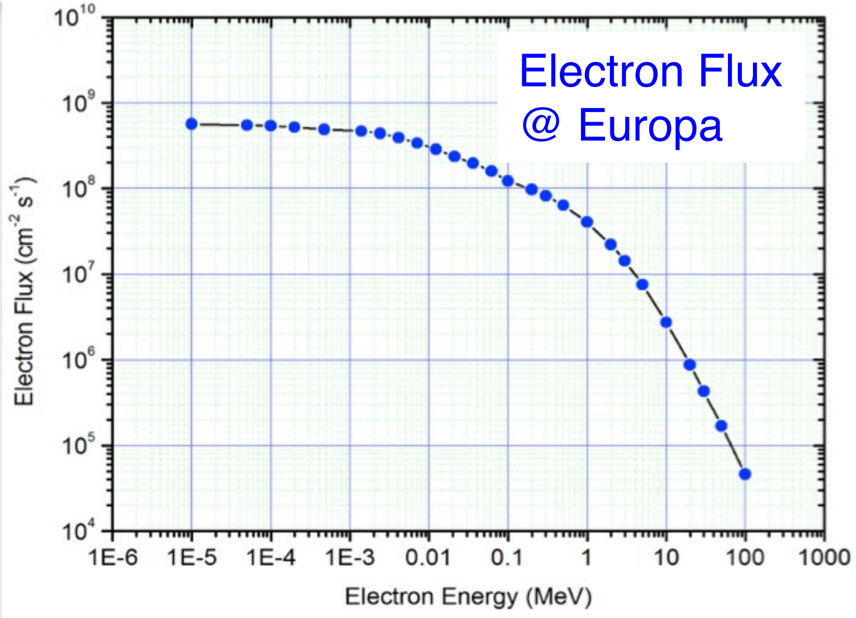
100 cm penetration:
1000 MeV electrons or
10 MeV X-rays

Electrons: http://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html
X-rays: http://www.nist.gov/pml/data/xraycoef/index.cfm

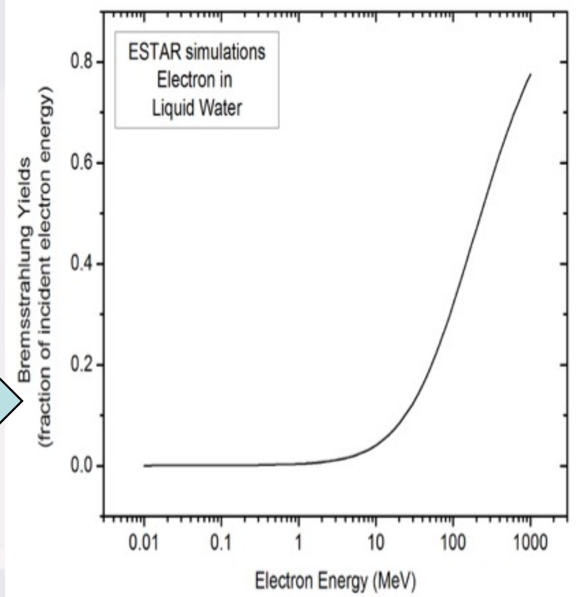
Bremsstrahlung the Secondary Radiation

Higher the electron energy, Shorter the X-ray (γ-ray) wavelength, Deeper the penetration of X-rays.

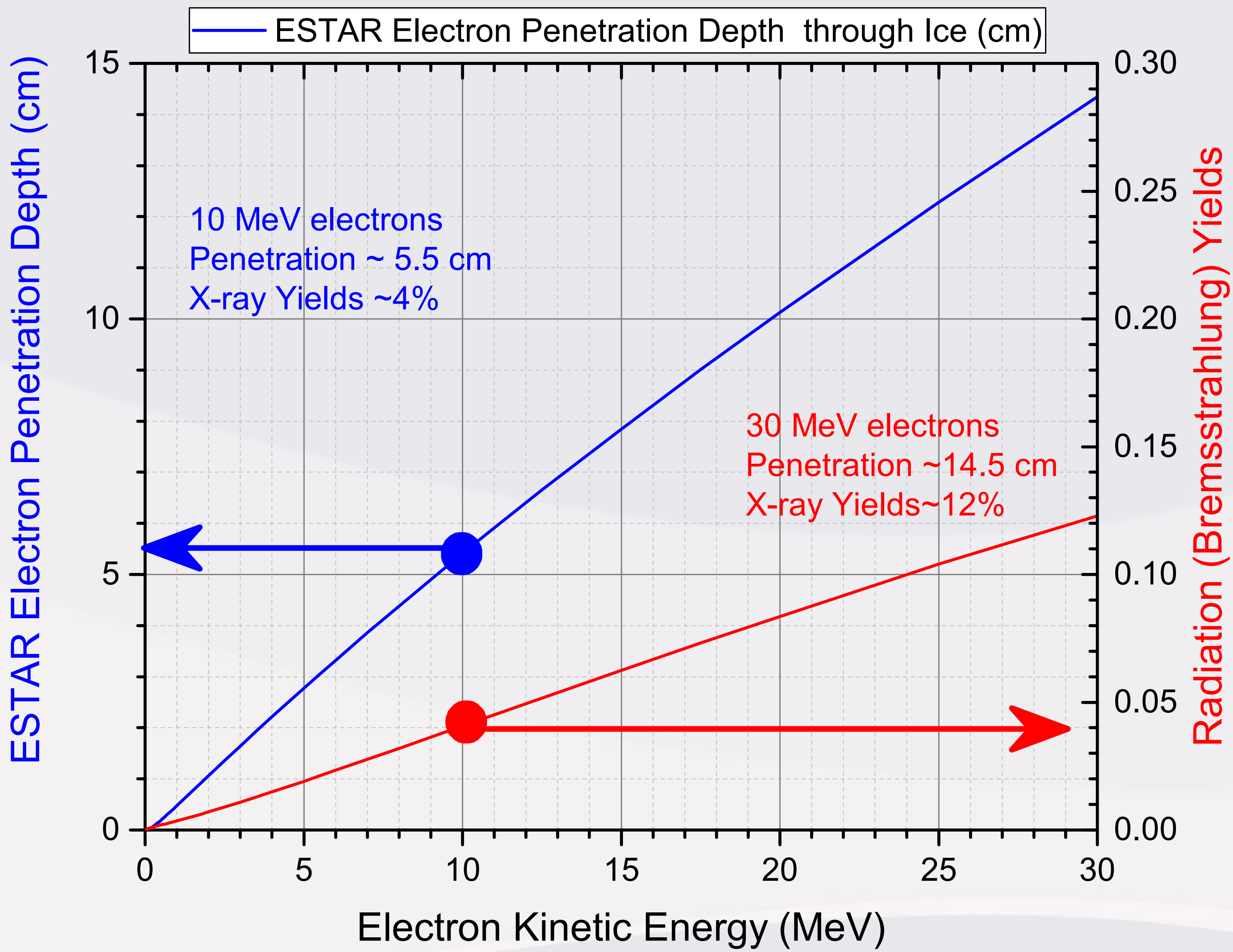




Bremsstrahlung Yields:
100 keV e^- ~1%
1 MeV e^- ~2%
10 MeV e^- ~5%
100 MeV e^- ~20%



Empirical Models: Bremsstrahlung (X-ray) Yields



How Good are Models without realistic Experiments?

Modeling Studies were based on:

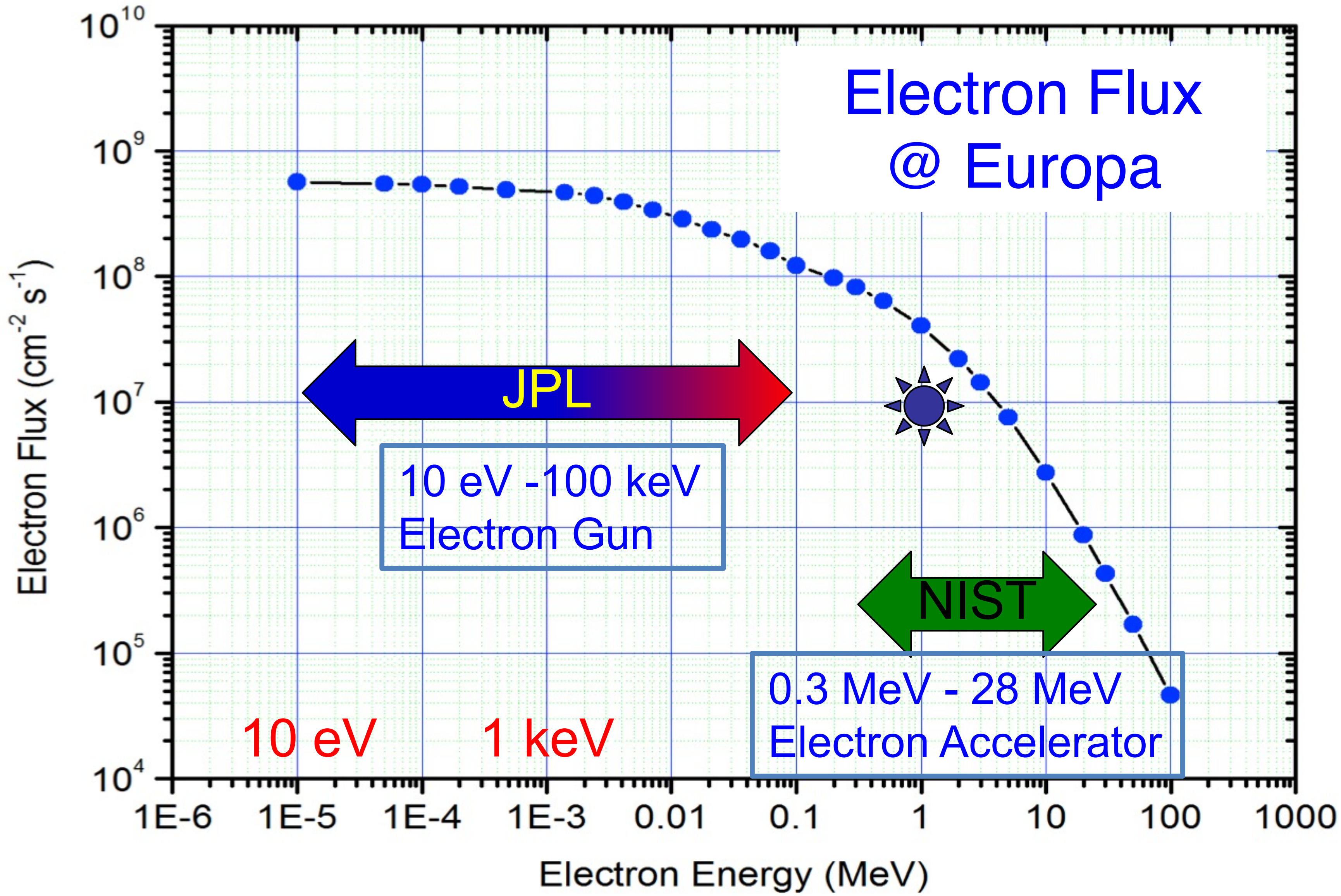
Liquid water and other non-ice targets.

Energies different from Europa's surface.

Extrapolations were done to estimate under Europa's conditions.

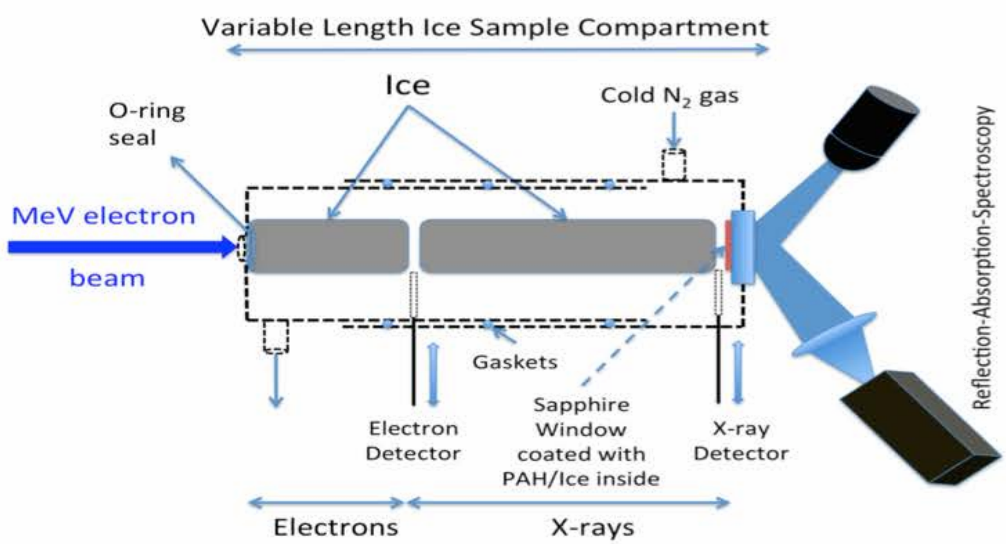
Until We Started Our Laboratory Studies At the Ice Spectroscopy Lab (ISL) of JPL

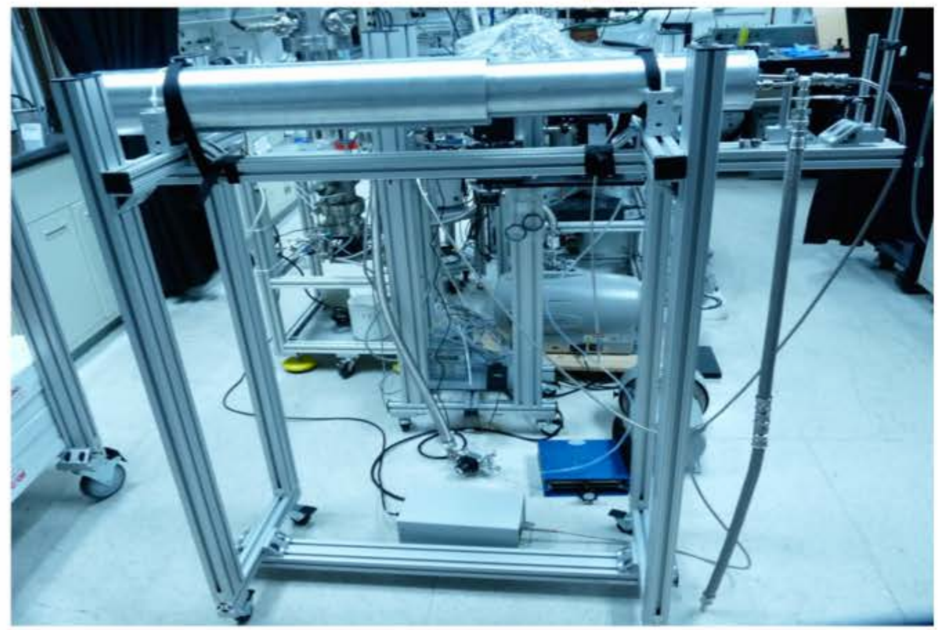
Present Capabilities of the ISL @ JPL



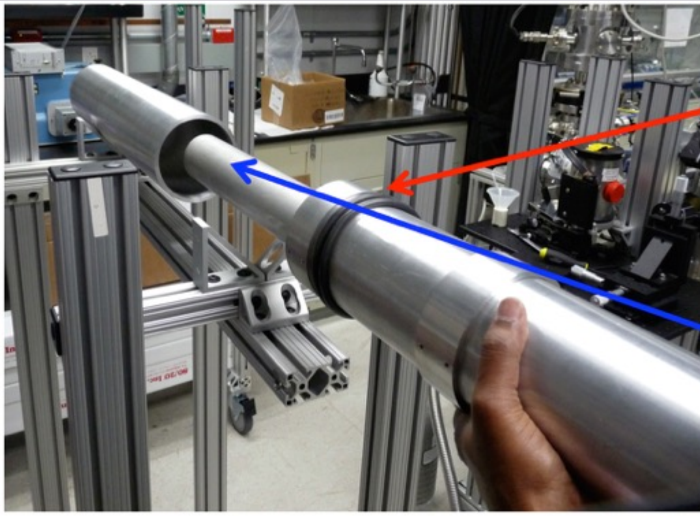
(Ice Chamber for Europa;s High-Energy Electron And Radiation-Environment Testing)

Designing and building ICE-HEART for Europa



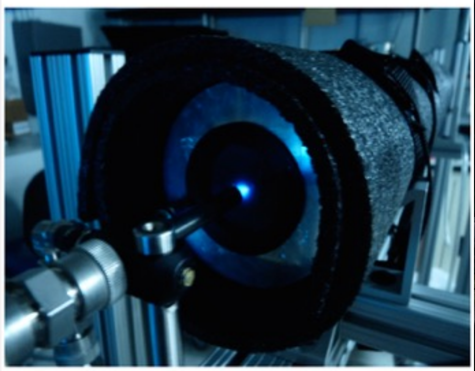


ICE-HEART

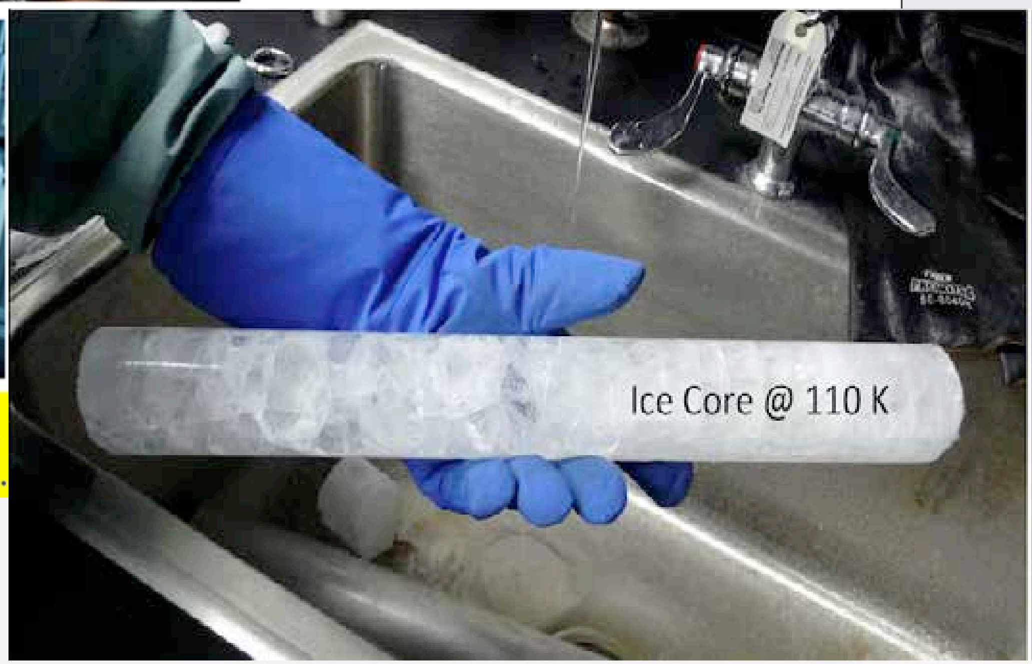


Outer Telescope with vacuum seal O-rings.

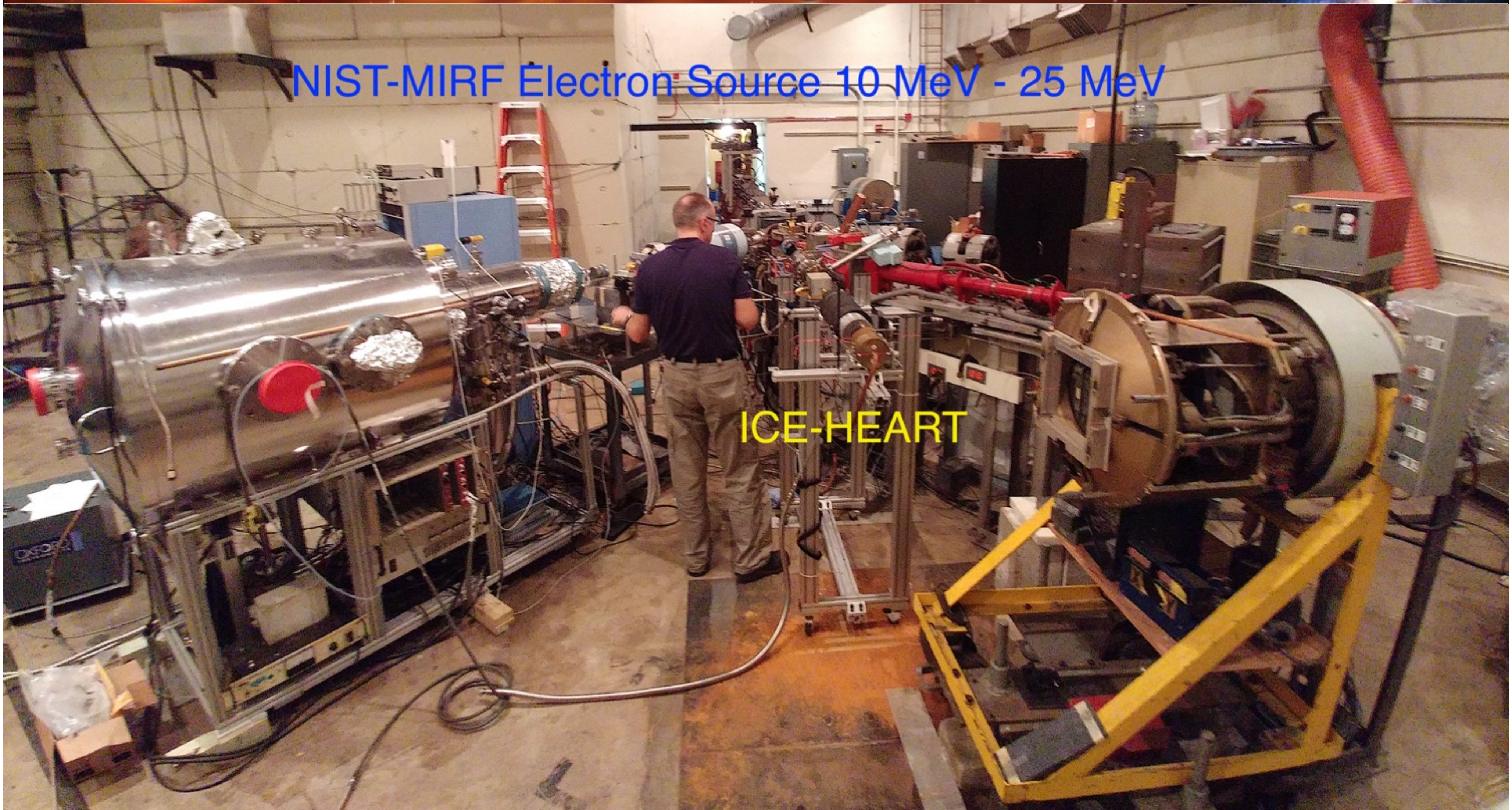
Inner 2.5-inch diameter tube for water ice frozen in the tube or loaded as crushed powder.



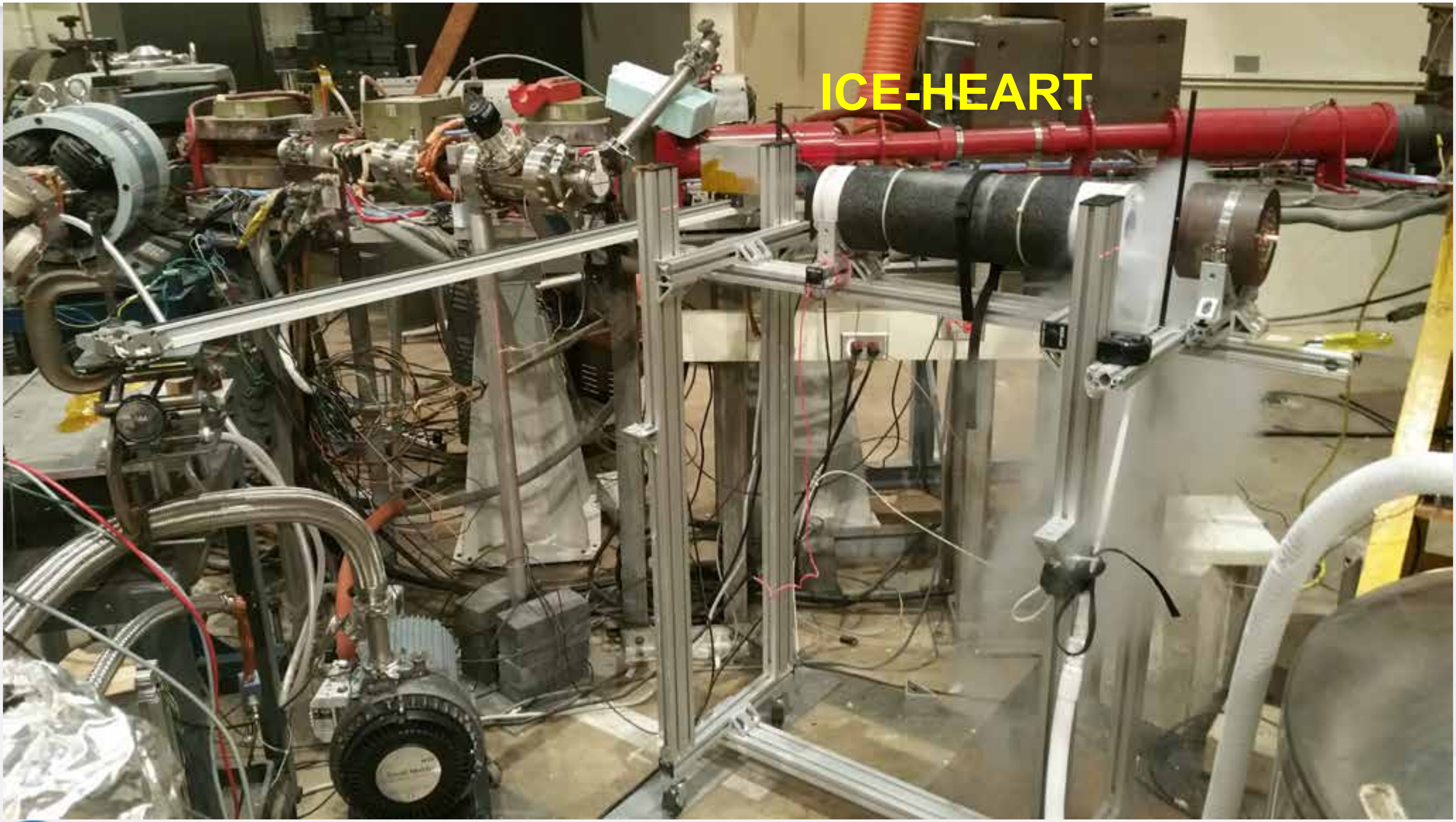
Insulated for 100 K operation
Using liquid nitrogen cooling.



NIST Electron Sources Cover 300 keV to 28 MeV



NIST Electron Sources Cover 300 keV to 28 MeV

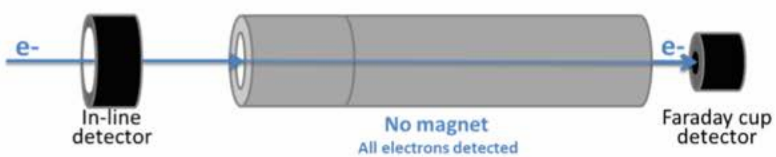


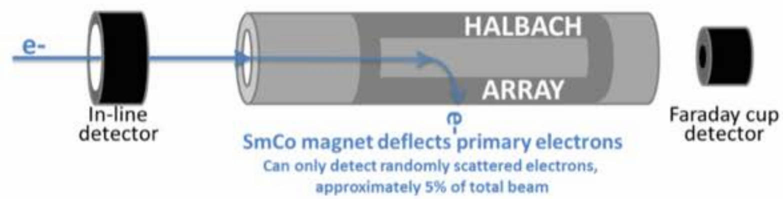
ICE-HEART Crew in Action @ NIST MIRF

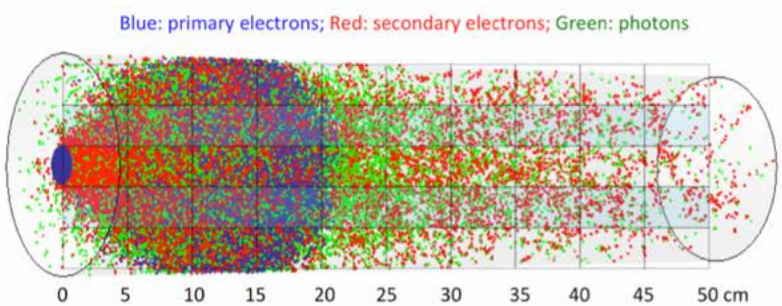
Ice Sample Handling in (subsequent to) High-Radiation Environment

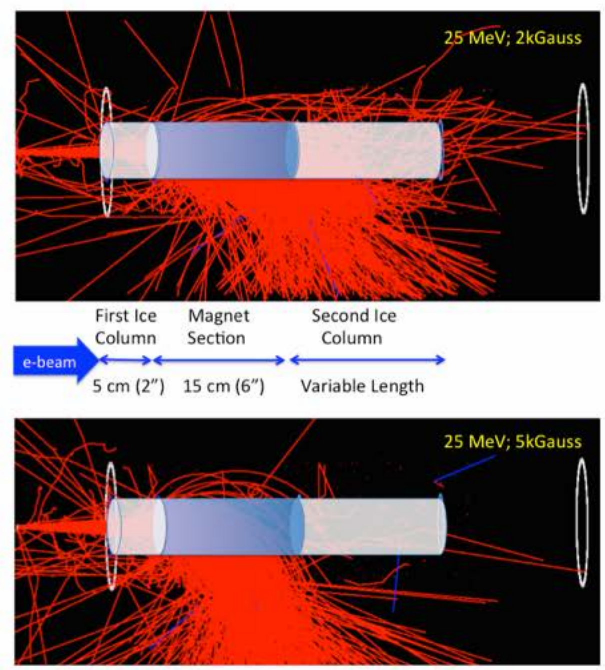
How to Quantify Bremsstrahlung (X-rays)?
By Removing Secondary Electrons

First Successful Incorporation of Halbach Cylindrical Magnet Deflecting Primary and Secondary Electrons Enables Quantification of X-ray Yields and Penetration Depths







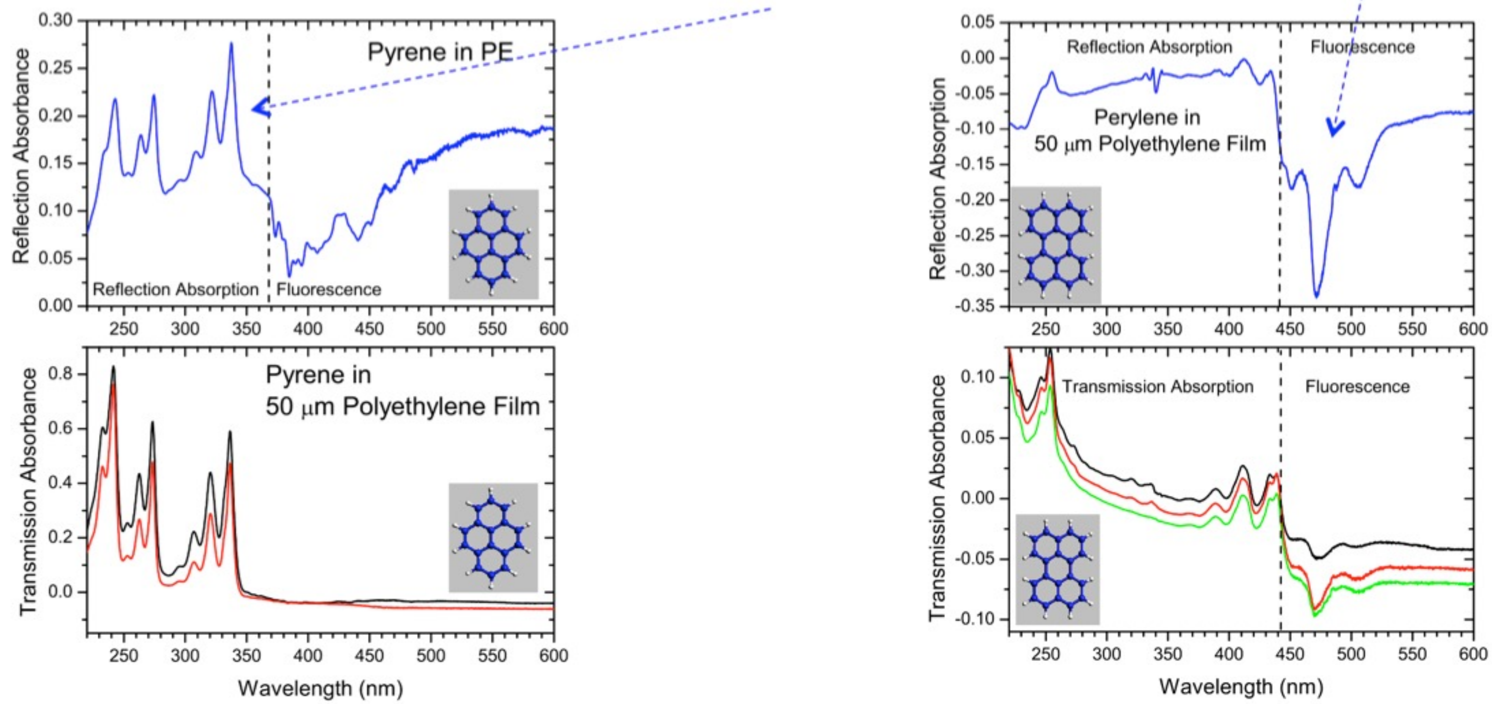


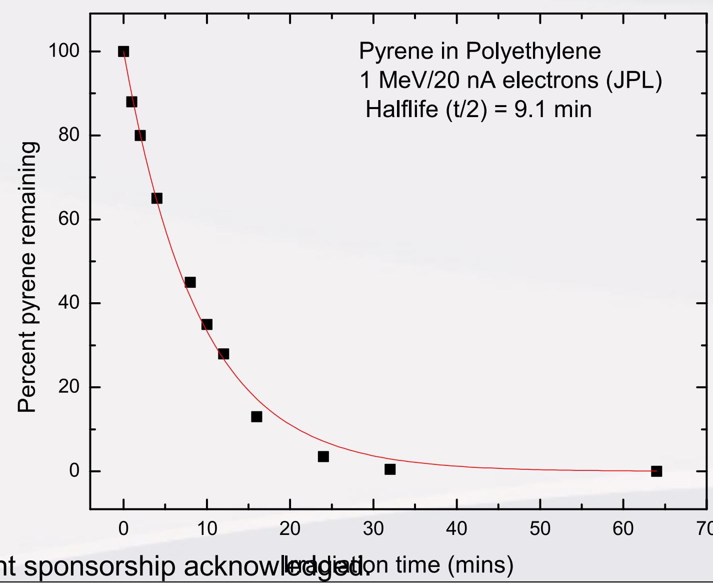
Above: typical secondary particle generation in the ICE-HEART when high energy electrons impinge upon ice with no magnet.

Right: Inserting a strong SmCo magnet (5 kGauss) into the chamber causes electrons to be deflected to the side, so that they no longer impinge upon the detector.

Organic Damage by 1MeV Electrons

Two Organic Probes: Strongly Absorbing (Pyrene); Strongly Fluorescent (Perylene)

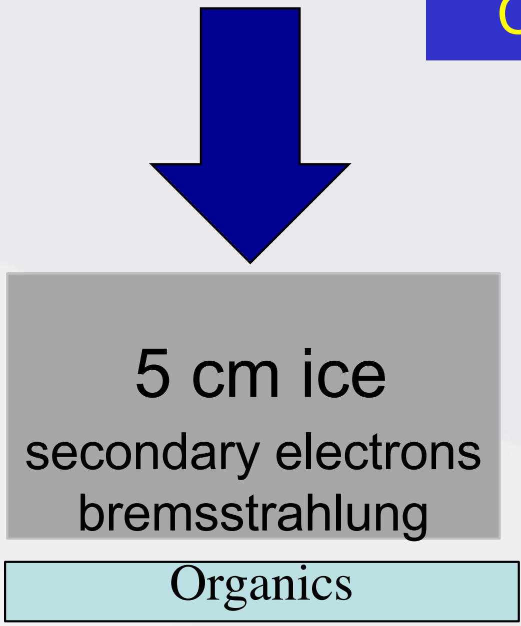




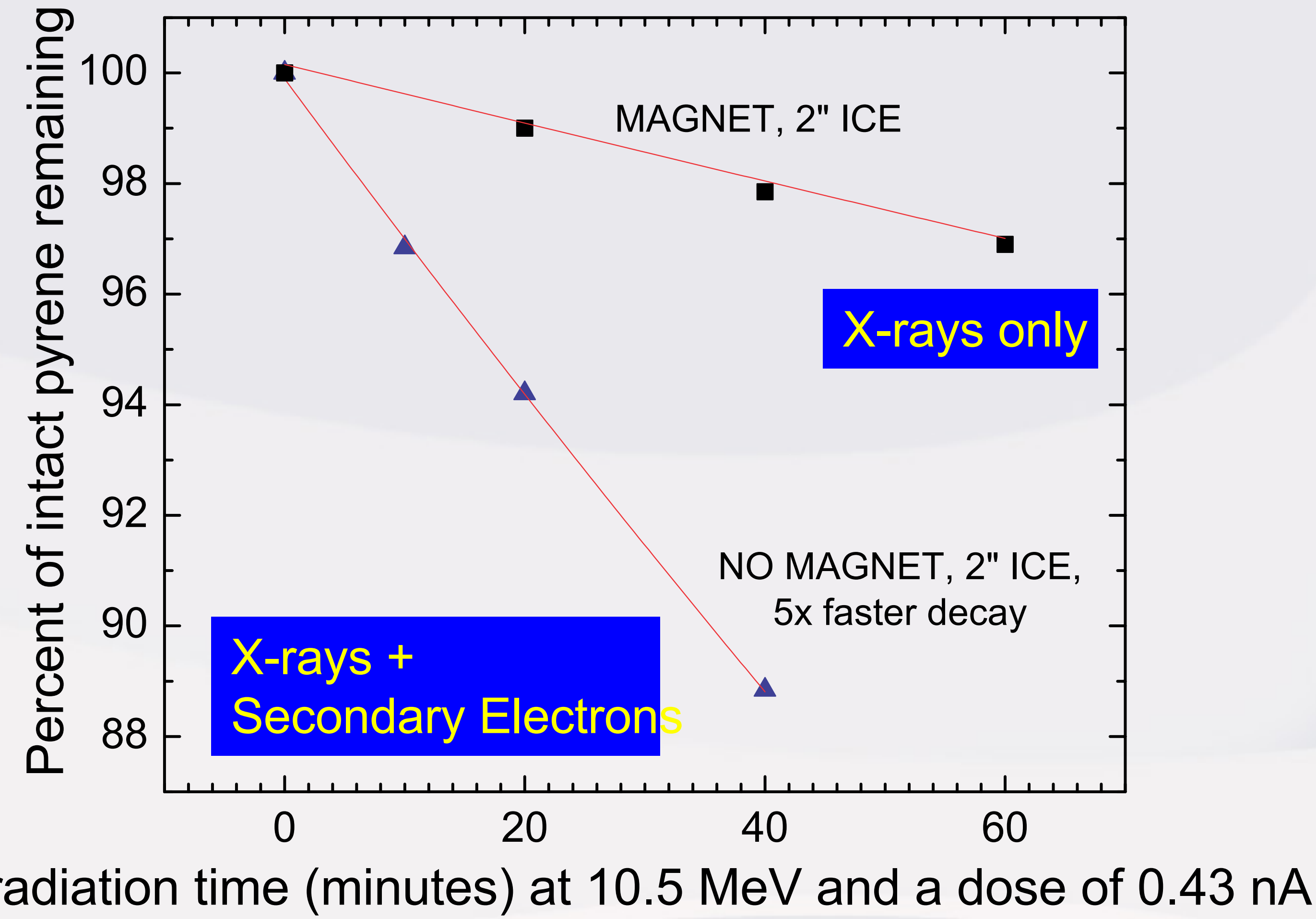
Secondary Electrons vs. X-rays

First JPL-NIST MIRF Data for 10 MeV Primary Electrons bombarding 5 cm thick ice targets at 100 K
Simulating Europa's Surface Radiation Damage of Organics
Critical for Future Lander Missions & Surface Habitability

10 MeV electrons

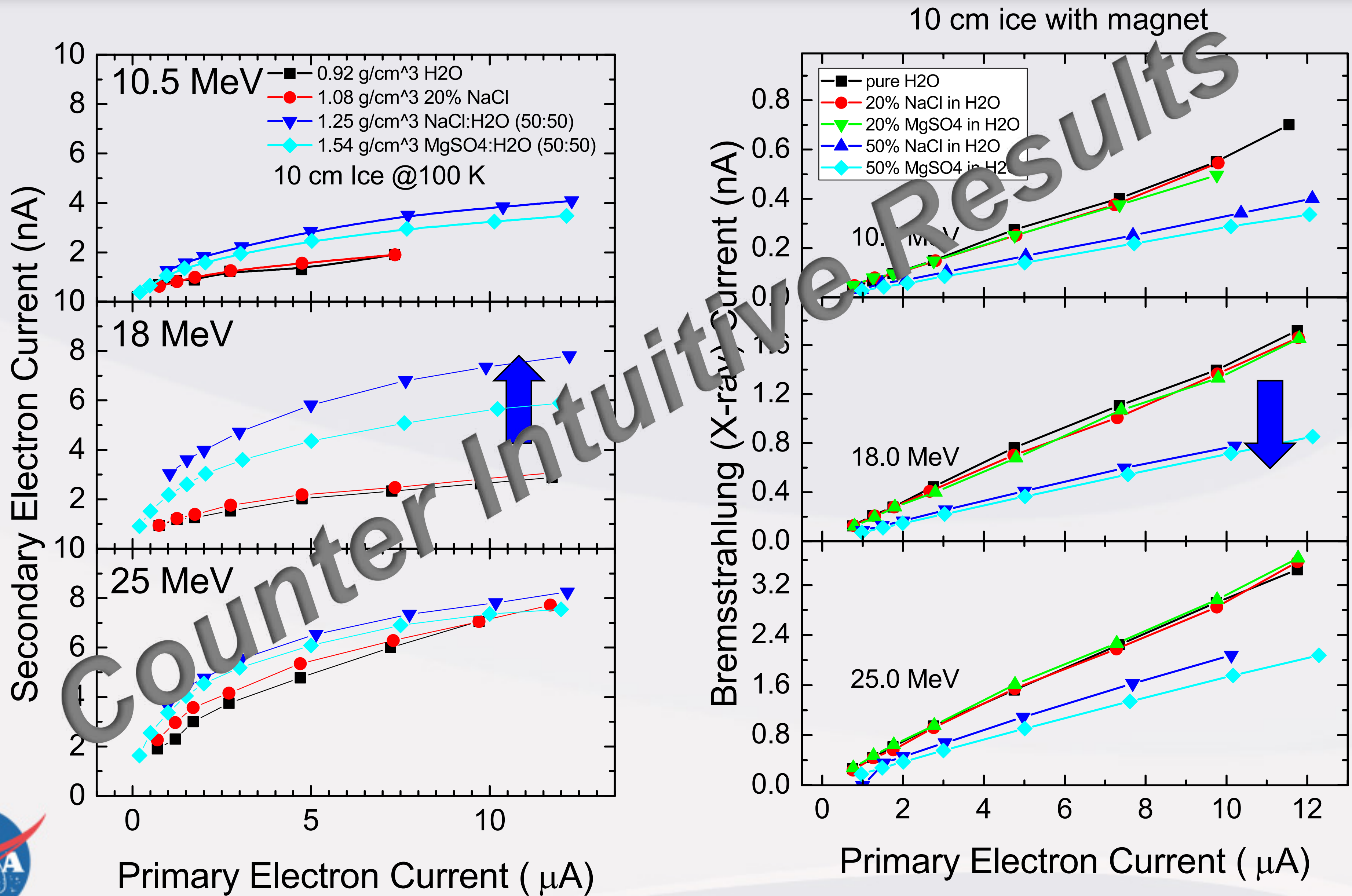


Damage through
sec. ele. 80%; X-rays 20%



Europa Ice Analogs (10 cm) with NaCl & $MgSO_4$

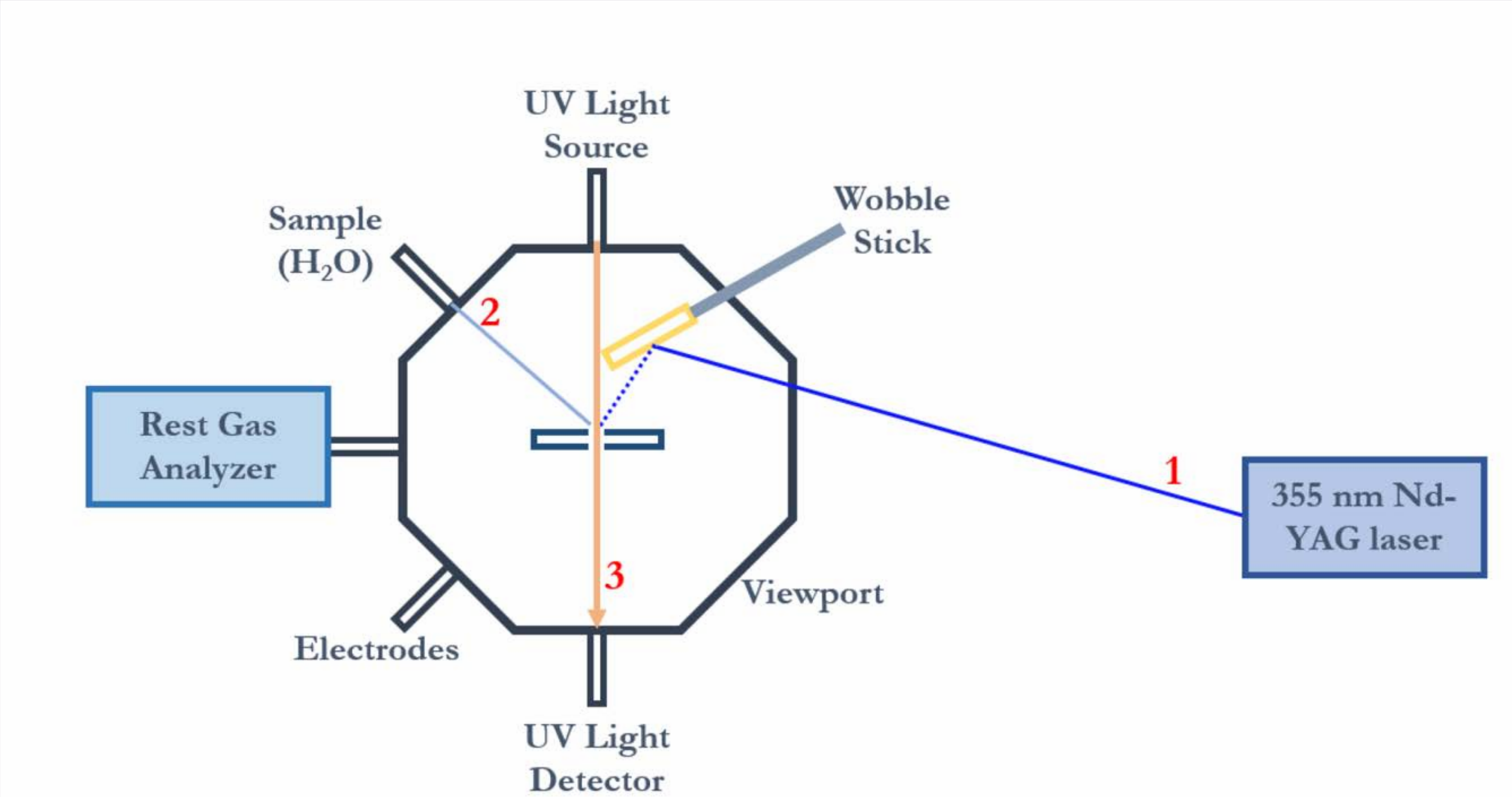
Secondary Electrons | Bremsstrahlung



Salts on Europa

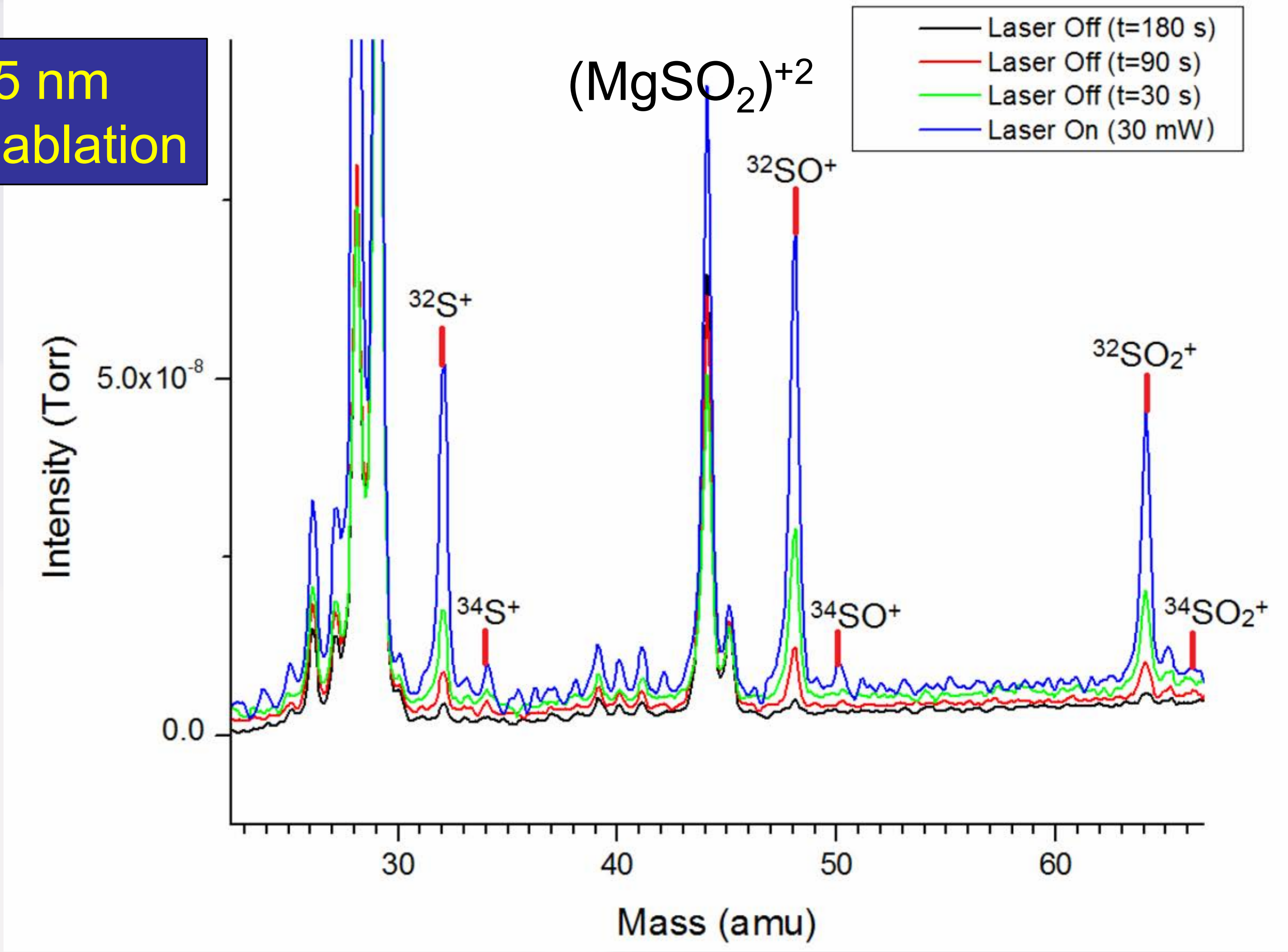
Sulfates & Chlorides
(Mg, Na, ??)

High Radiation Environment: Volatiles from Salts on Europa

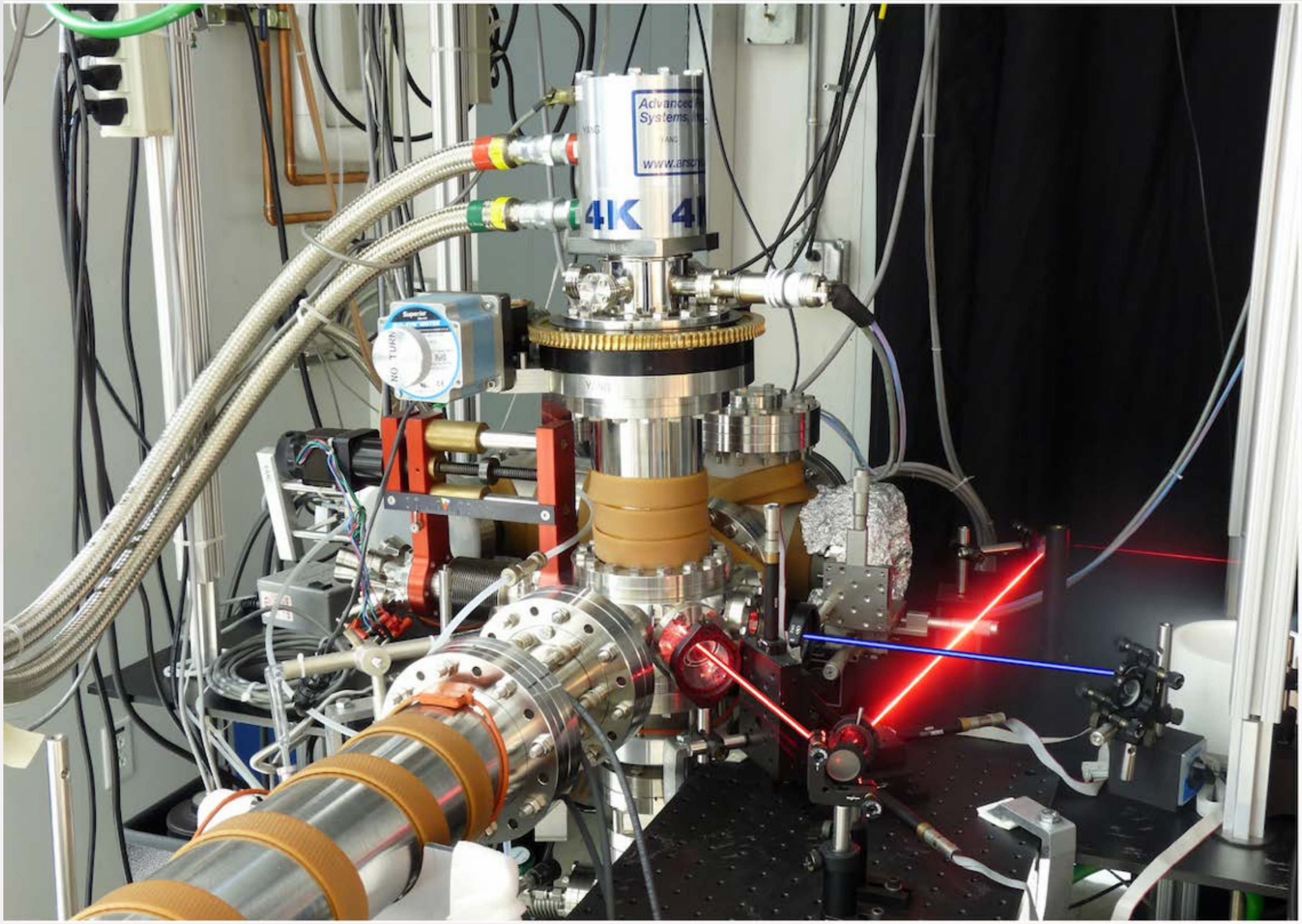


High Radiation Environment: Volatiles from $MgSO_4(7H_2O)$ on Europa

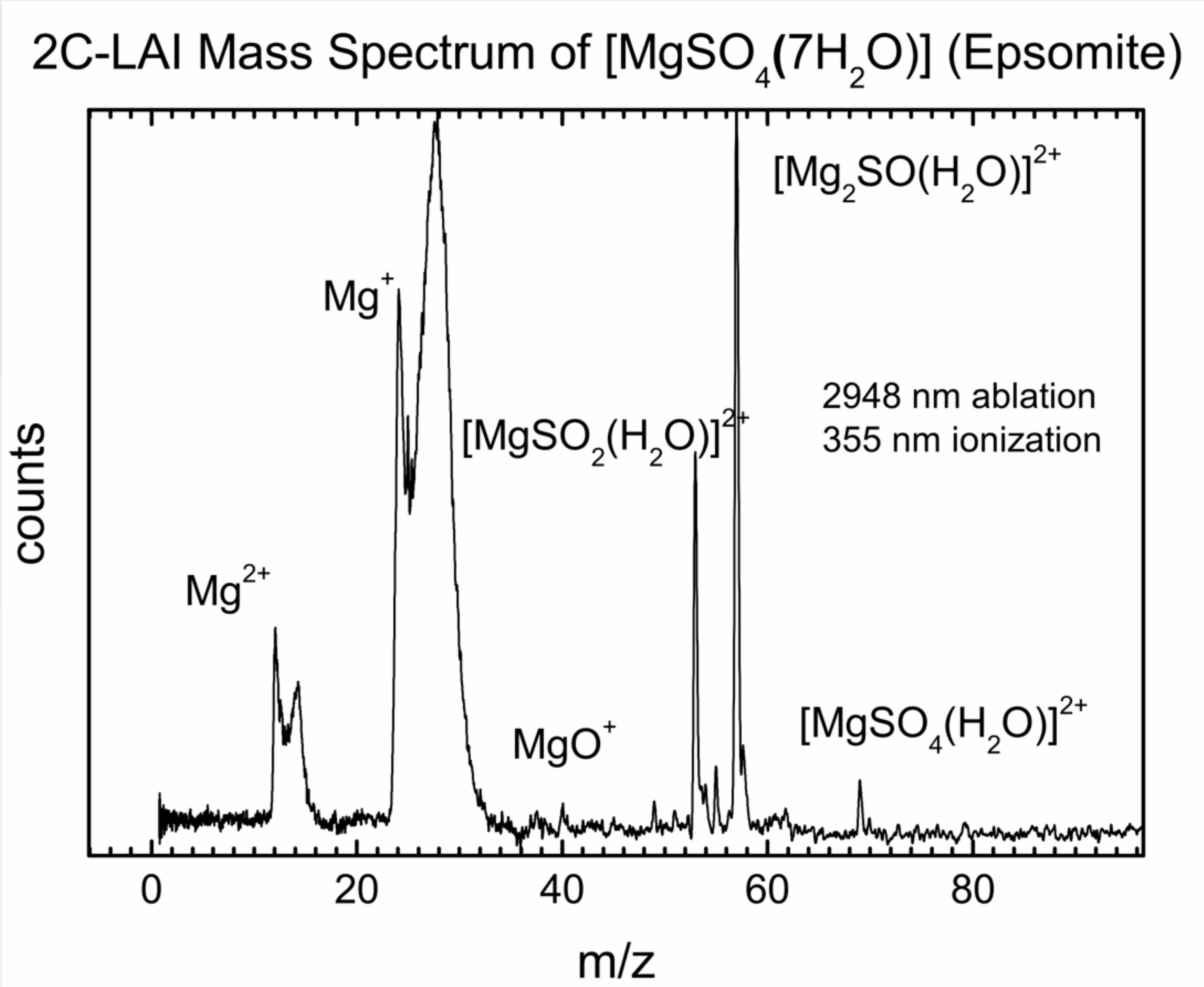
355 nm
Laser ablation



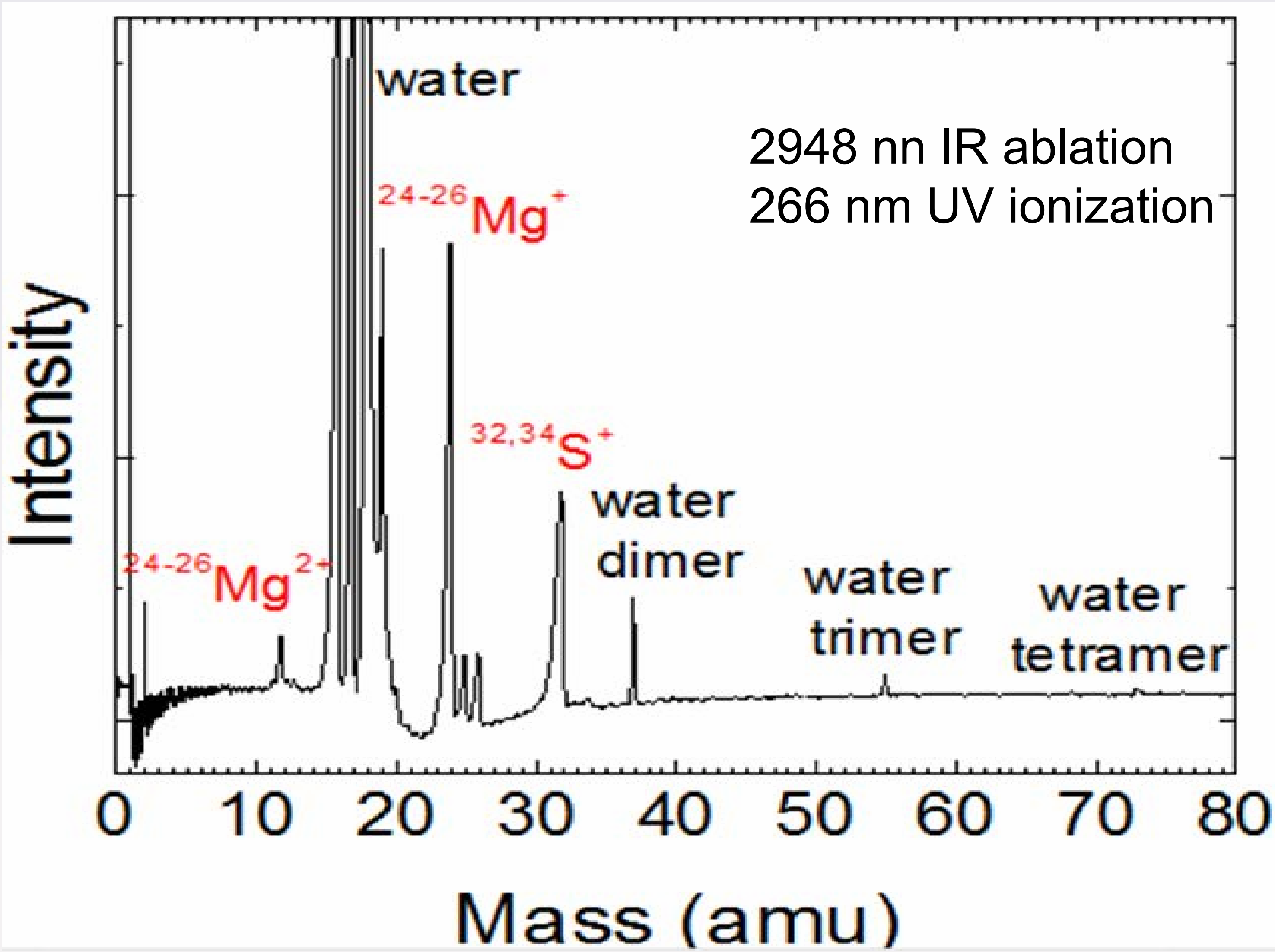
Low Radiation Environment: Volatiles from Salts on Europa



Low Radiation Environment: Volatiles from Salts on Europa



Low Radiation Environment: Volatiles from Salt-Slurry on Europa



Physical Properties of Europa's Surface Ice

We are presently conducting laboratory studies to understand physical properties of ice and salts at MeV radiation environment

Ice (+ Salts):

a) Hardness with/without MeV Radiation
b) Coloration with/without MeV Radiation
c) Chemical composition alteration under MeV Radiation

Conclusions & Future Work

Preliminary Conclusions

- Secondary photons (X-rays) could penetrate up to 1m deep on trailing hemisphere of Europa (close to the equator).
- Bremsstrahlung (secondary photons) damage to organics is NOT INSIGNIFICANT (~20%)
- Secondary Electron Yields are HIGH in Salts (vs. pure ice)
- Bremsstrahlung (secondary photons) Yields are LOW in Salts (vs. pure ice)
- Surface composition of Europa would be dictated by the altitude dependent geological activity. Geologically inactive regions are expected to be heavily processed.

Future Work

- A lot to do and to publish a lot of results
- Funding (?) so far unsuccessful from several attempts with NSPIRES

Contributors and Resources

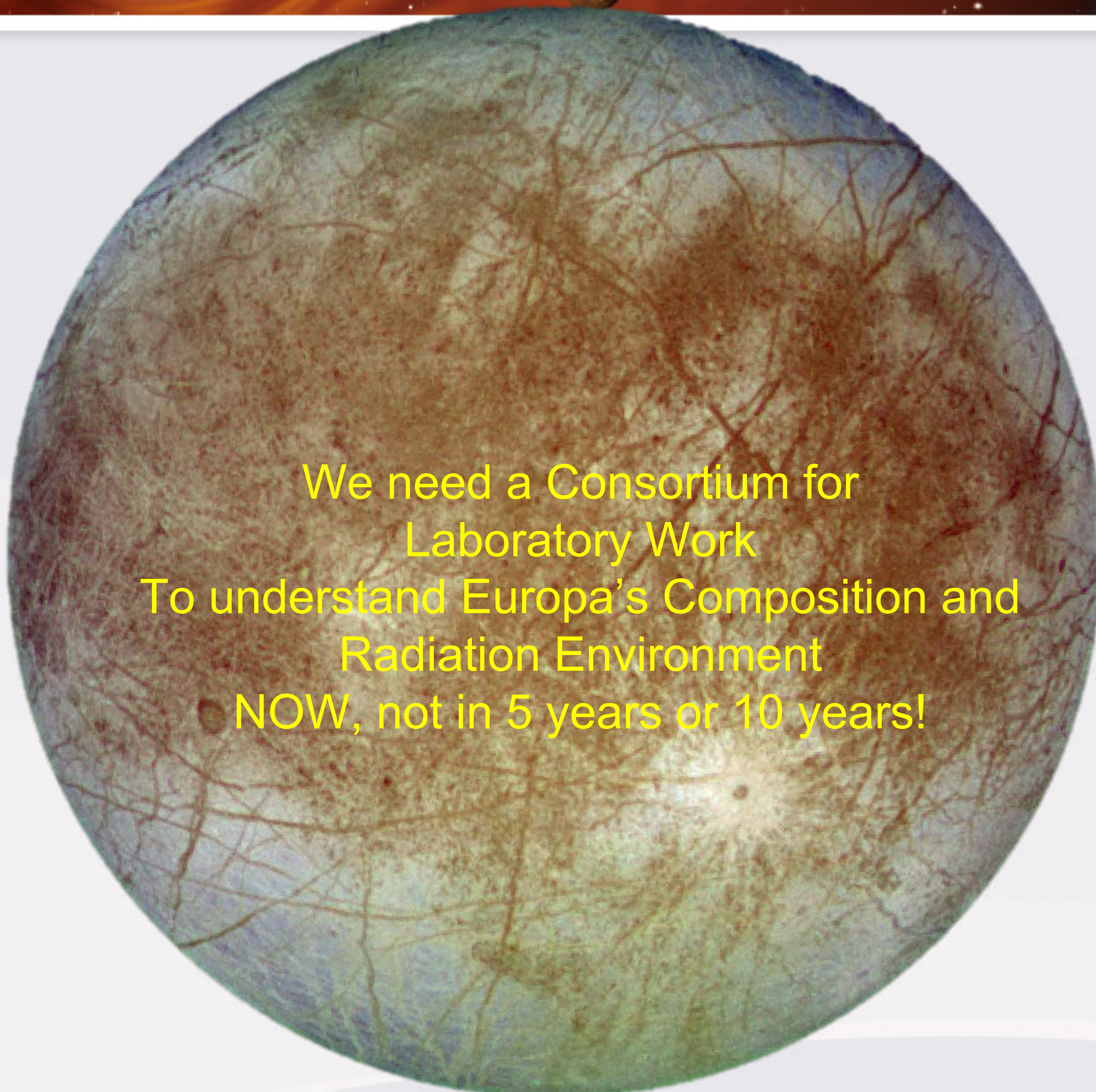
ICE-HEART Team

Murthy Gudipati (JPL)
Bryana Henderson (JPL)
Fred Bateman (NIST)

Consultants:
Shawn Kang (JPL)
Henry Garrett (JPL)

Funding: JPL Research and Technology
FY14-FY16

The END



We need a Consortium for
Laboratory Work
To understand Europa’s Composition and
Radiation Environment
NOW, not in 5 years or 10 years!

Backup

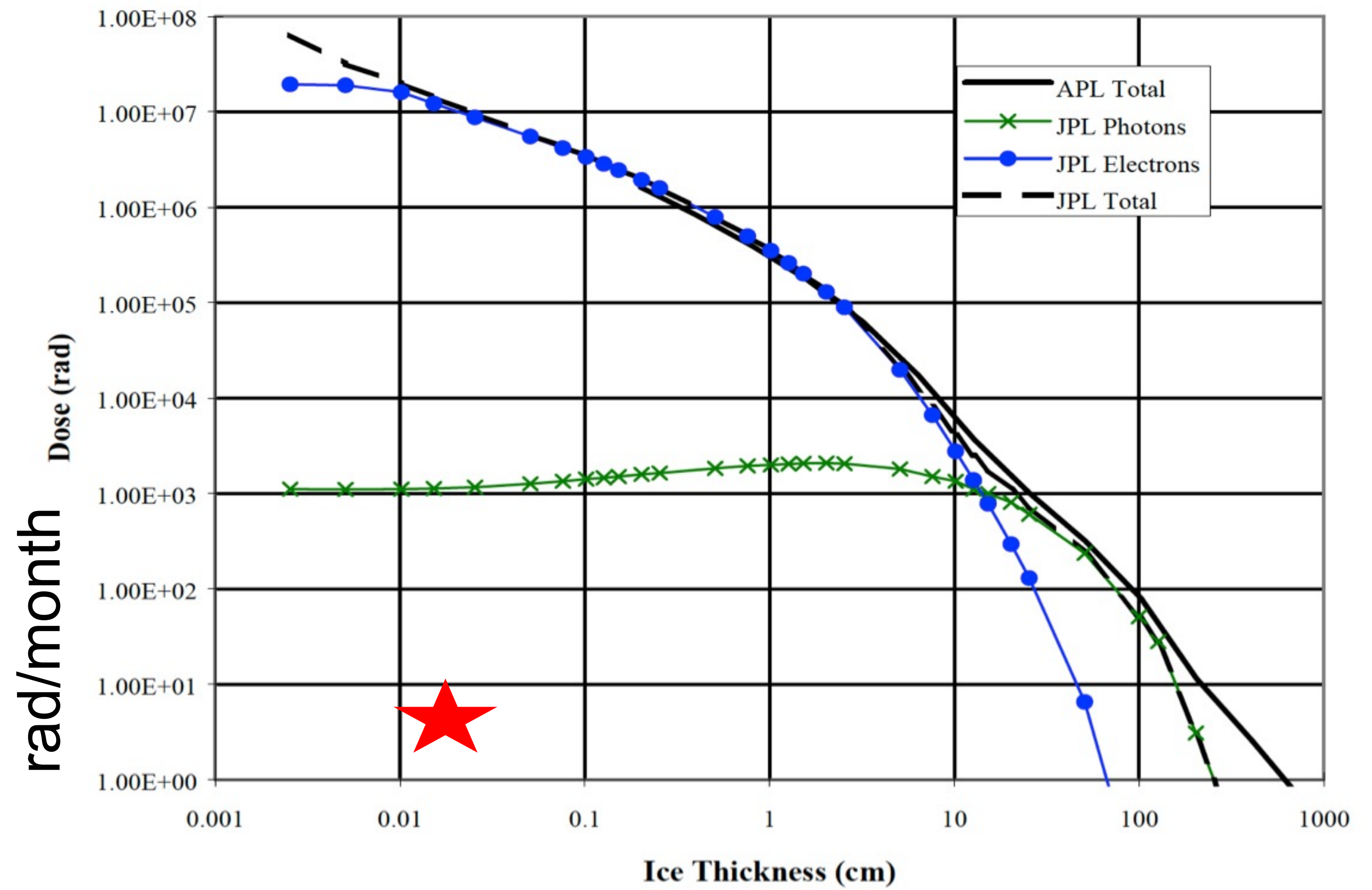
Radiation Units and Confusions

Quantity	Name	Symbol	Unit	Year	System
Exposure (X)	röntgen	R	esu / 0.001293 g of air	1928	non-SI
Absorbed dose (D)			erg•g^{-1}	1950	non-SI
	rad	rad	100 erg•g^{-1} (0.01 J/kg)	1953	non-SI
	gray (=100 rad)	Gy	J•kg^{-1} (6.24 x 10^18 eV/kg)	1974	SI
Activity (A)	curie	c	3.7×10^{10} s^{-1}	1953	non-SI
	becquerel	Bq	s^{-1}	1974	SI
Dose equivalent (H)	röntgen equivalent man	rem	100 erg•g^{-1}	1971	non-SI
	sievert	Sv	J•kg^{-1} (100 rem)	1977	SI
Fluence (Φ)	(reciprocal area)		cm^{-2} or m^{-2}	1962	SI (m^{-2})

1 rad = 6.24 x 10^{13} eV g^{-1}; 60 million 1 MeV electrons

Max permissible dose for humans (astronauts) = 25 rem/year

Models suffering from lack of experimental data



Preventing the Forward Contamination of Europa, National Academy of Sciences Report, 2000.

FIGURE 2.3 Radiation dose models for Europa, in rad [water] per month (30.4 days) of exposure below varying thicknesses of ice. The results of two independent evaluations are given, "JPL Total" and "APL Total." For the

1 rad =1 rem = 6.24 x 10^{13} eV g^{-1}; 2.28 x 10^{-8} eV/H_2O/year

Max permissible dose for humans (astronauts) = 25 rem/year

Radiation Dose in the Laboratory

1 μA = 10^{-6}Coloumbs/s = 6.242×10^{12} Electrons or Protons per second

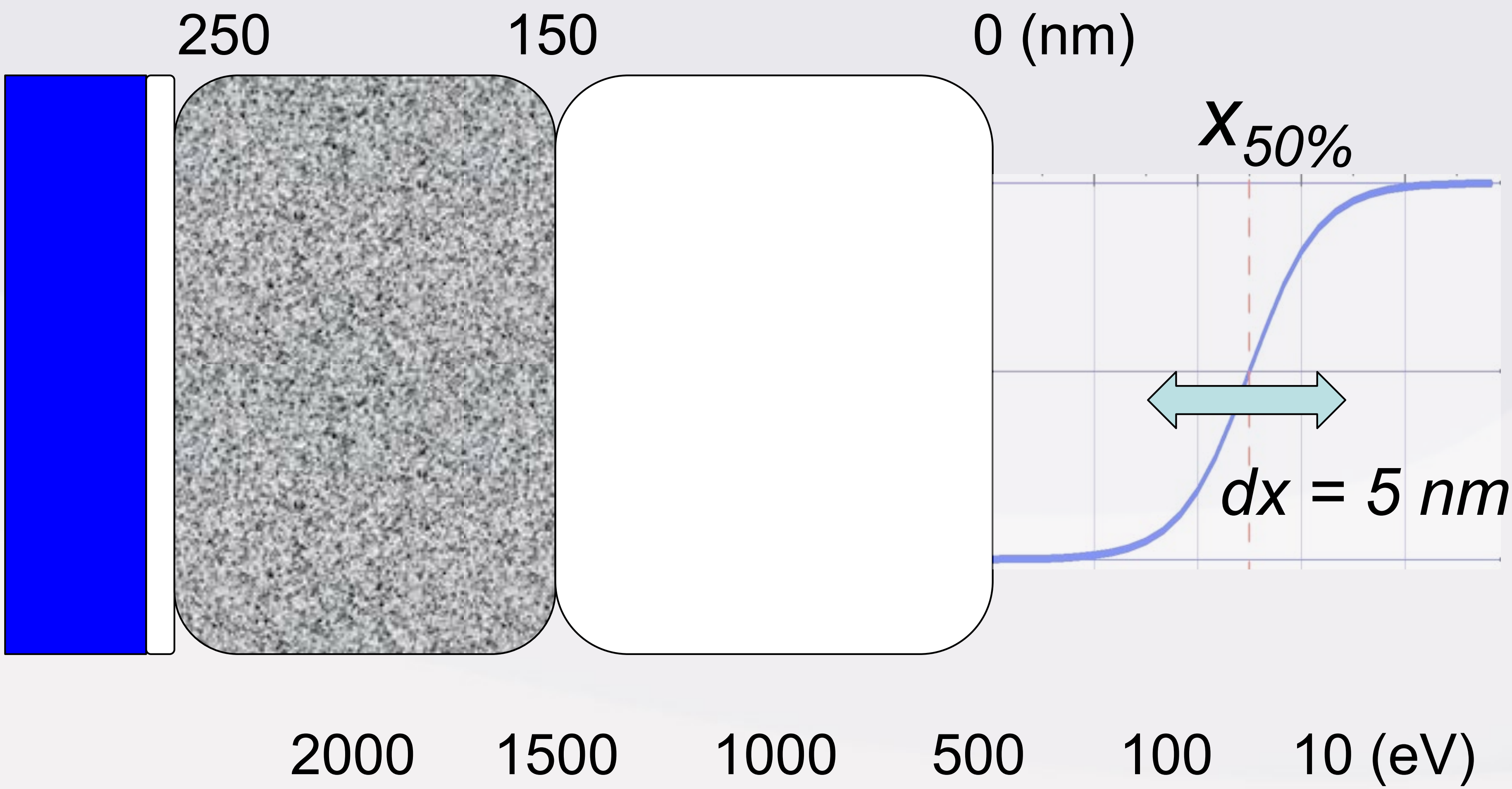
1 rem = 1 rad = 6.24×10^{13} eV g^{-1} =

1 μA of 10 eV electrons
OR
60 million 1 MeV electrons
OR
6×10^{6} 10 MeV electrons

Max permissible dose for humans (astronauts) = 25 rem/year

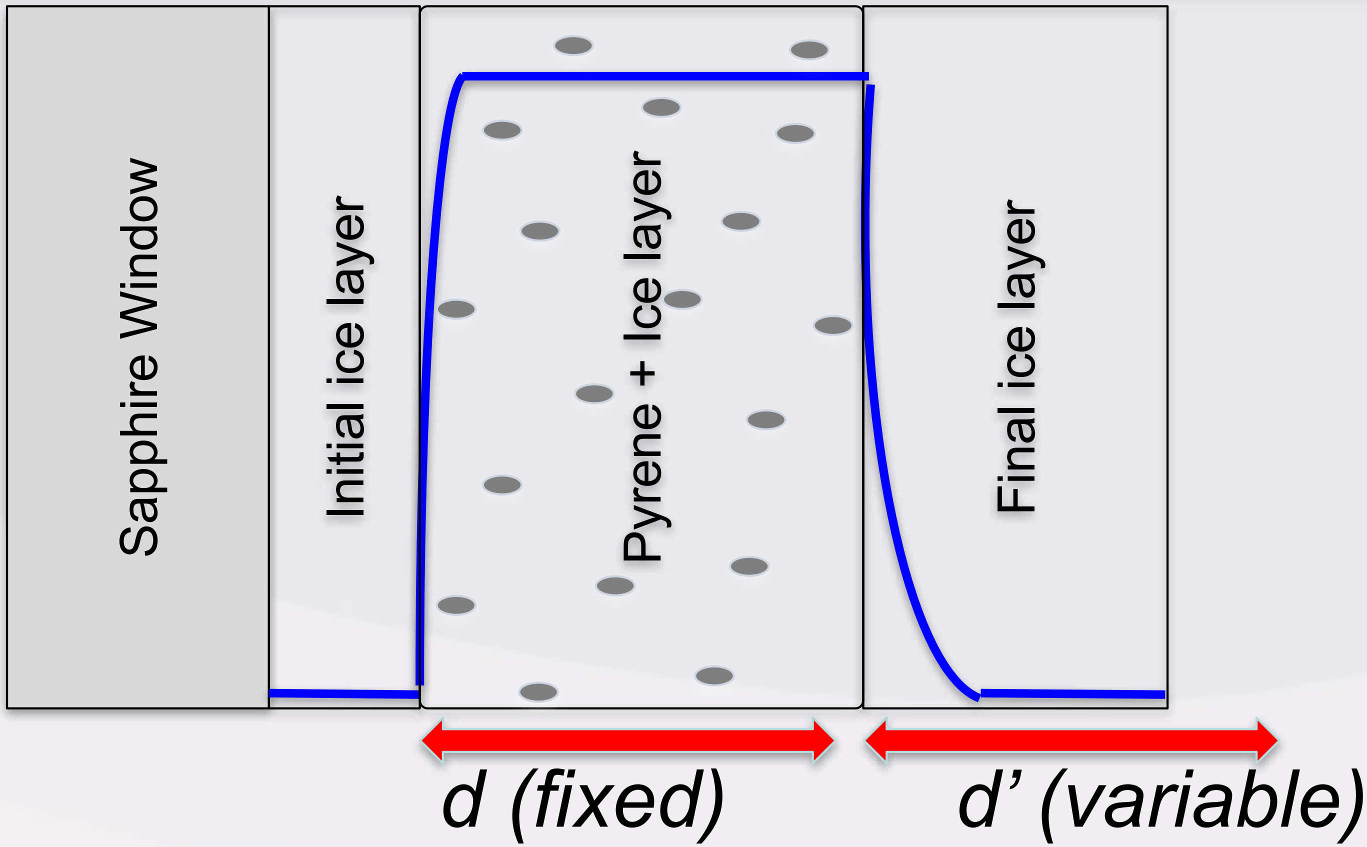
(Equivalent to ~0.15 nA or 1.5×10^{8} electrons per gram at 10 MeV)

Electron Penetration Depth is a Sigmoidal Function (not a delta function)



Li Barnett, Lignell, Gudipati ApJ 747:13 (11pp), 2012

Modeling electron induced organic damage

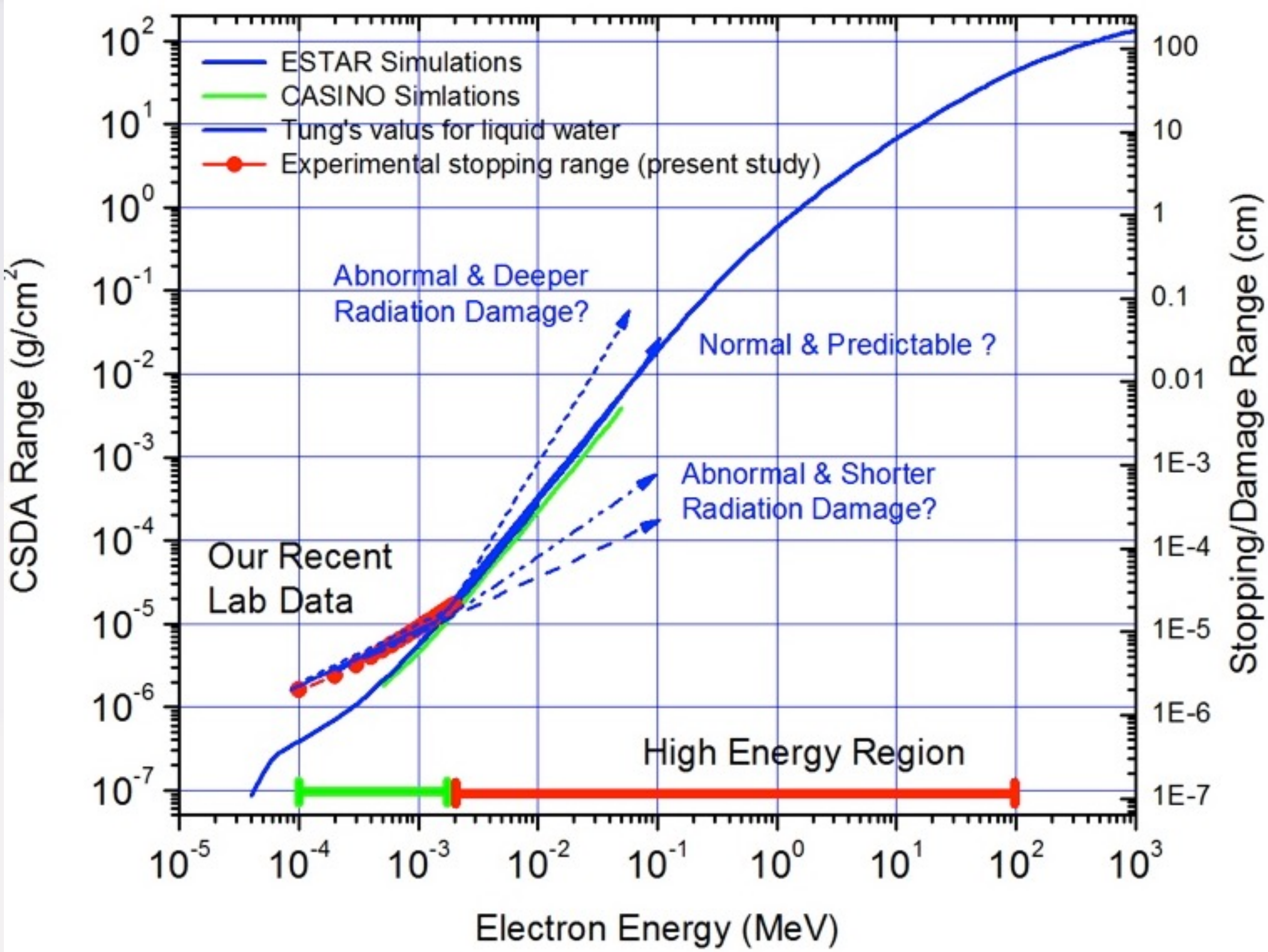


$$PD_{\mathrm{sum}} = \int_{x=0}^{x=d1} \left(\frac{A_1 - A_2}{1 + e^{(x-x_0)/dx}} + A_2 \right) * \mathrm{Cl}$$
$$+ \int_{x=d1}^{x=d2} \left(\frac{A_1 - A_2}{1 + e^{(x-x_0)/dx}} + A_2 \right) * C2 + \ldots$$

Organics Damage Depths in Ice by Electrons

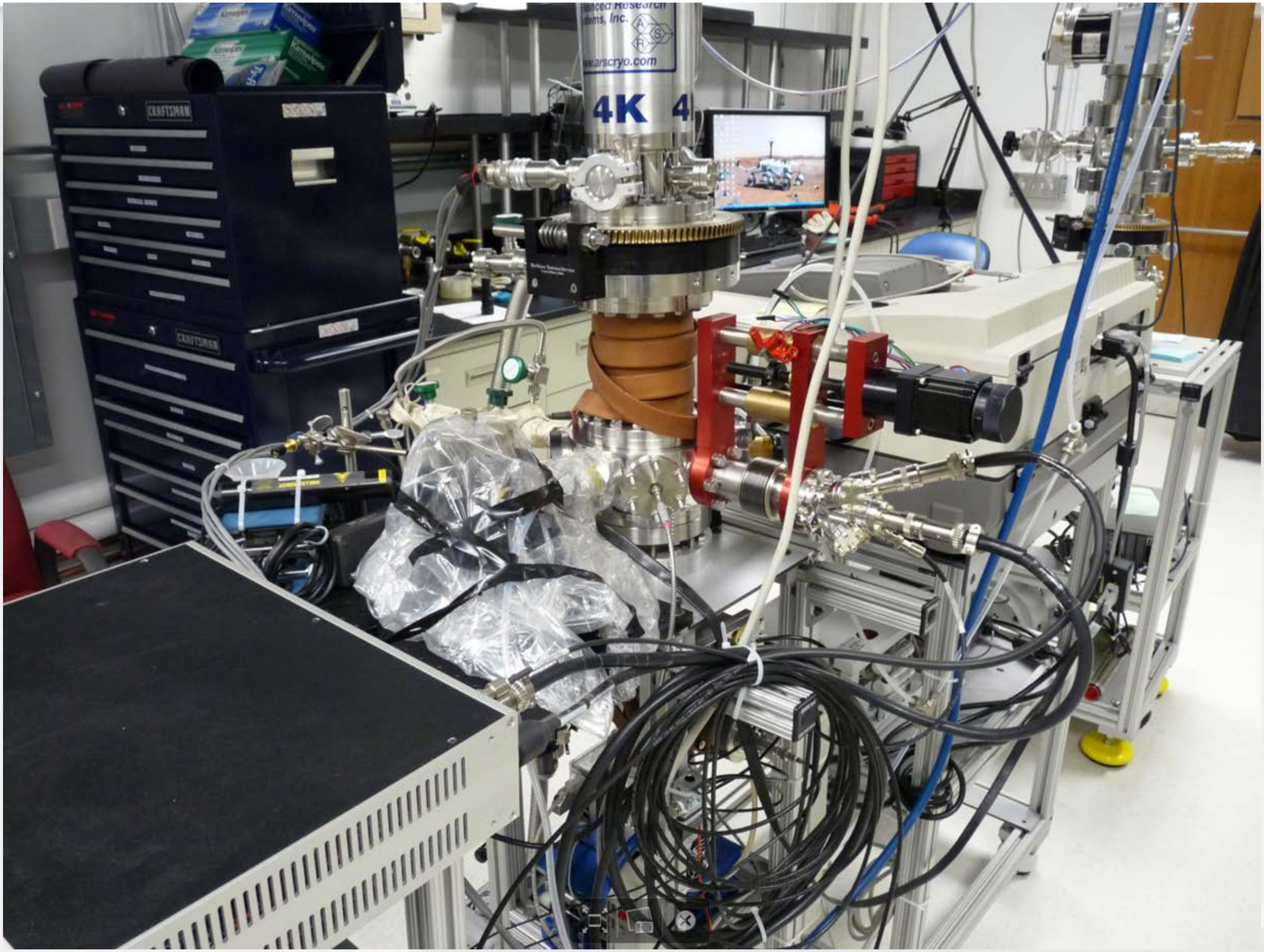
Except for our work, no experimental data is available for electron and secondary radiation damage depths in ice.

Models use extrapolated values from liquid water and other solids.



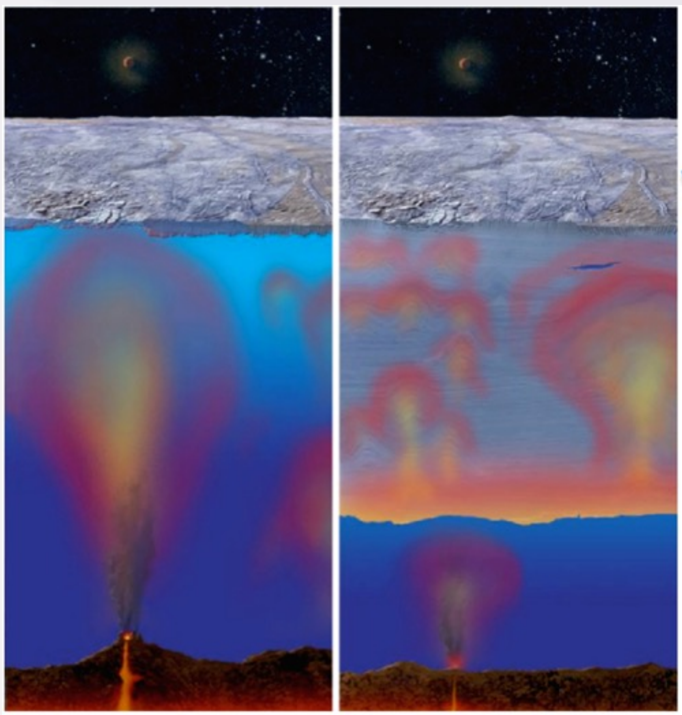
Li Barnett, Lignell, Gudipati ApJ 747:13 (11pp), 2012

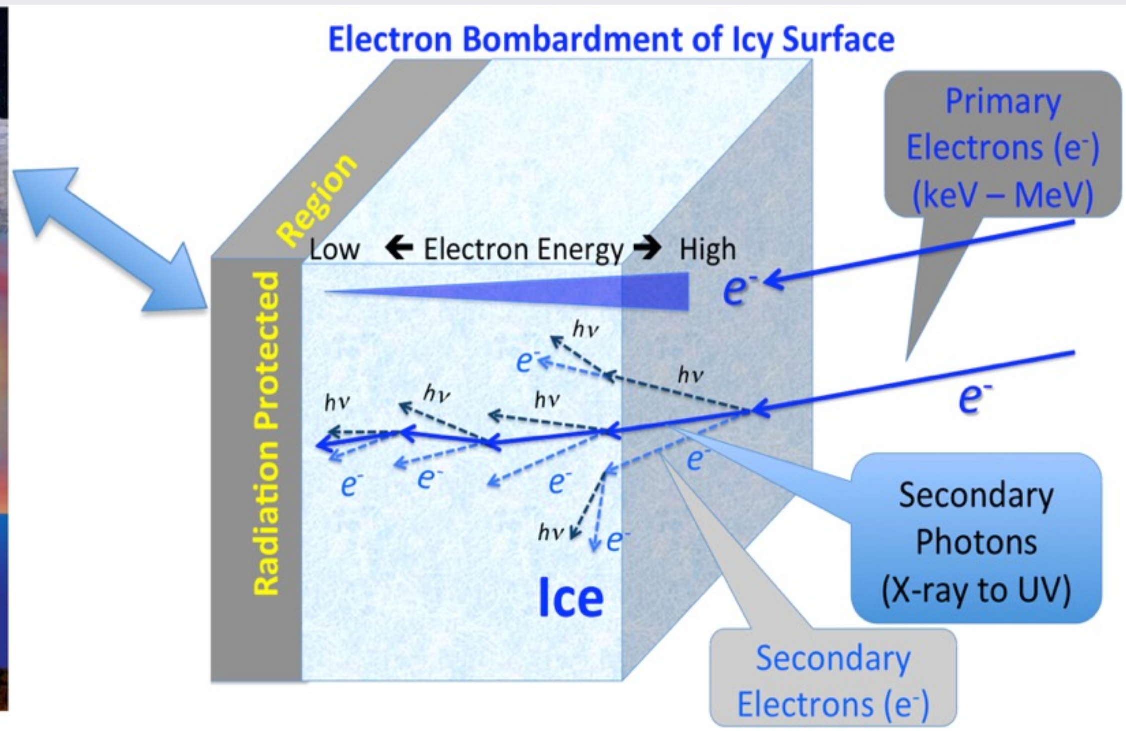
Europa Organic Radiation Processing Studies @ Ice Spectroscopy Lab



Laboratory Research Needs for Europa Clipper

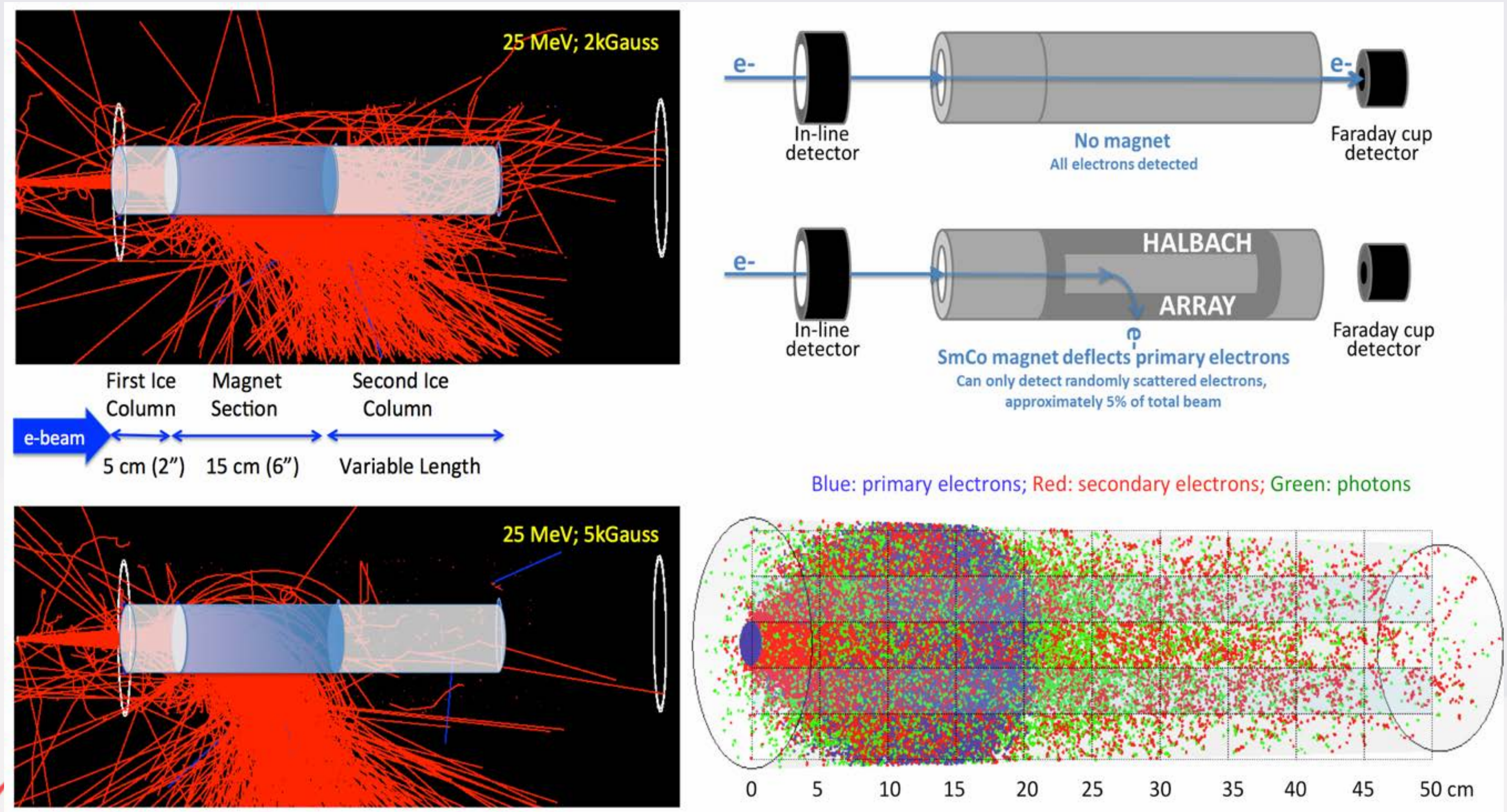
- **Radiation budget/properties on Europa's (near)Surface**
- Surface composition under radiation
- Near-surface ice composition
- Radiation processing of organics on/near surface
- Sputtering of surface/near-surface material
- Potential Plume Composition
- Subsurface ice, liquid, vents, and rock composition/chemistry



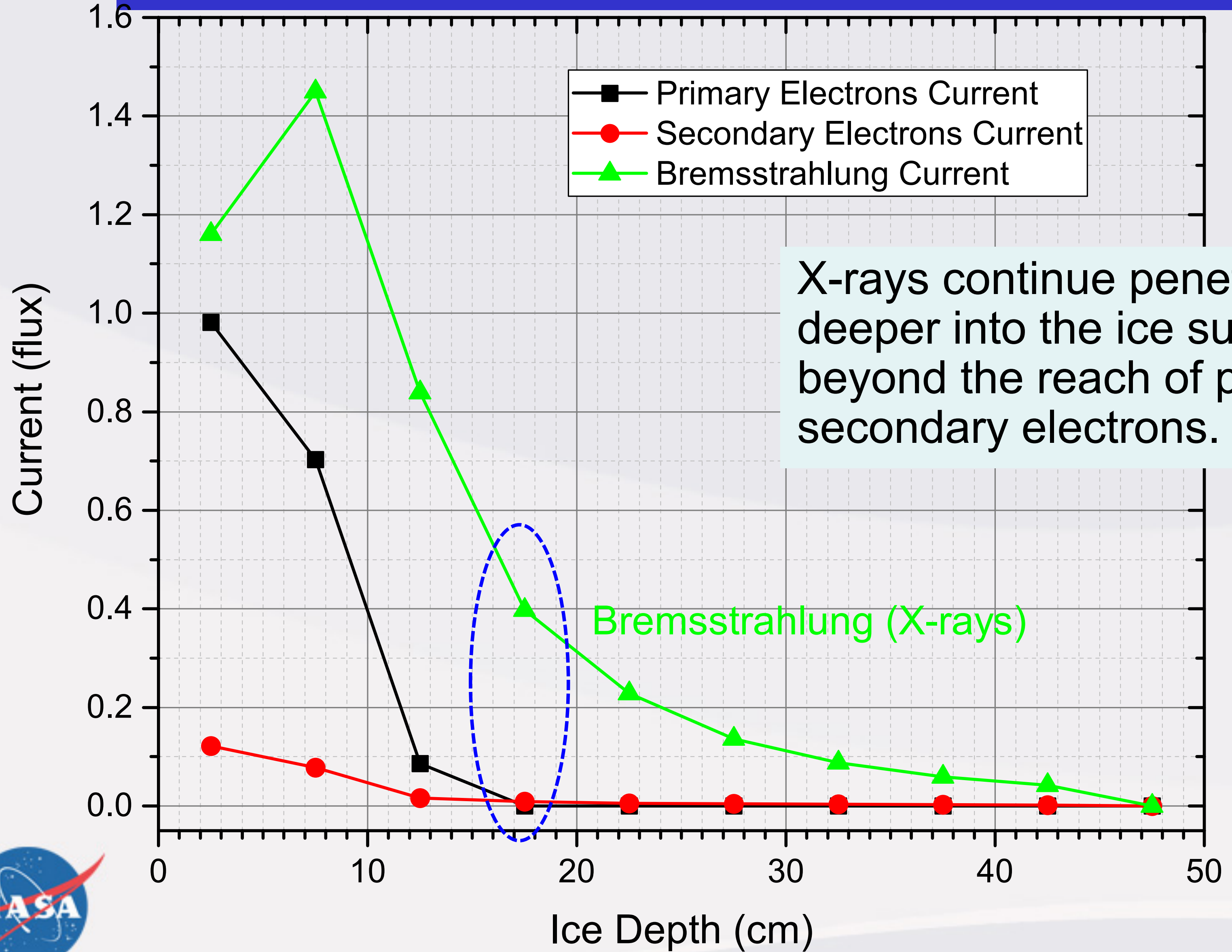


Quantification of Bremsstrahlung (X-rays)

First Successful Incorporation of Halbach Cylindrical Magnet Deflecting Primary and Secondary Electrons Enables Quantification of X-ray Yields and Penetration Depths



GEANT Simulation of 30 MeV Primary Electron yields of Secondary Electrons and Bremsstrahlung (X-rays) at various Depths through Ice



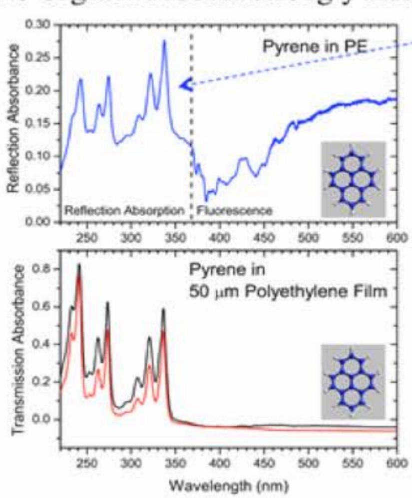
X-rays continue penetrating deeper into the ice surface beyond the reach of primary and secondary electrons.

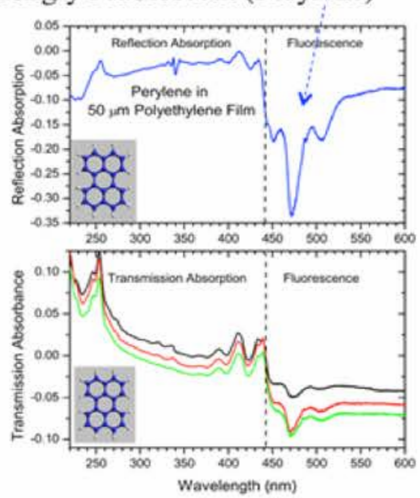
ICE-HEART: Realistic Europa's Surface Conditions

Testing ICE-HEART and quantifying radiation damage



Two Organic Probes: Strongly Absorbing (Pyrene); Strongly Fluorescent (Perylene)





UV-VIS Reflection Absorption Spectroscopy is used to quantify the radiation damage to exposed polyethylene films containing organic molecules.